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May 1997

US Army Corps of Engineers
Waterways Experiment Station

Monongahela Dam 4 Spillway, Pennsylvania

Hydraulic Model Investigation

by Deborah R. Cooper

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Prepared for U.S. Army Engineer District, Pittsburgh

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13. ABSTRACT *(Maximum 200 words)*

Monongahela Dam 4 is located on the Monongahela River 34.1 km (21.2 miles) upstream of the confluence of the Ohio, Allegheny, and Monongahela Rivers, in the city of Charleroi, PA. The existing dam maintains the navigation pool between the Dam 4 and Dam 5 locks and dams. Normal upper pool elevation for the Monongahela 4 is presently at el 743.5 (all elevations cited herein are in feet referred to the National Geodetic Vertical Datum). The existing spillway section of Dam 4 consists of a gated crest (el 724.0) located within the main channel of the waterway. Energy is dissipated ona horizontal apron with baffle blocks terminated by an end sill. The U.S. Army Engineer District, Pittsburgh,, developed a "two-for-three" plan for renovating locks and dams on the lower Monongahela River that would save the cost of having to reconstruct L&D 3 and reduce transportation costs by eliminating bottlenecks caused by the small locks at L&D's 3 and 4 and by reducing one lockage cycle. The plan calls for building a new gated dam at the current L&D 2, eliminating L&D 3, and replacing the locks at L&D 4 with new, larger locks. The change would also mean Pool 2 would be raised by about 1.5 m (5 ft) and the current Pool 3 would be lowered by about 1.0 m (3.2 ft) (lowering the tailwater for L&D 4 by 1.0 m (3.2 ft)). The dam consists of a navigable gated structure with three radial tainter gates and two piggyback gates. The original derrick stone placed below the structure has experienced significant scour. The future lower tailwater may result in more severe scour unless the condition is

(Continued)

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Energy dissipation	Spillway	Water-surface
Monongahela	Stilling basin	

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remedied. Additionally, a scour hole has developed in the streambed upstream of the dam. The spillway sectional model investigation was conducted to investigate the hydraulic performance of the structure under long-range operating conditions for controlled and uncontrolled flows. Specifically, the model study would provide the data necessary to evaluate and develop a satisfactory means of operating and protecting the structure from scour without creating adverse hydraulic conditions. The following information was obtained from the model: flow characteristics and stilling basin performance; rip rap requirements for protection downstream of the structure; and discharge characteristics and coefficient with various operation scenarios, including ice under flow and upstream scour potential.

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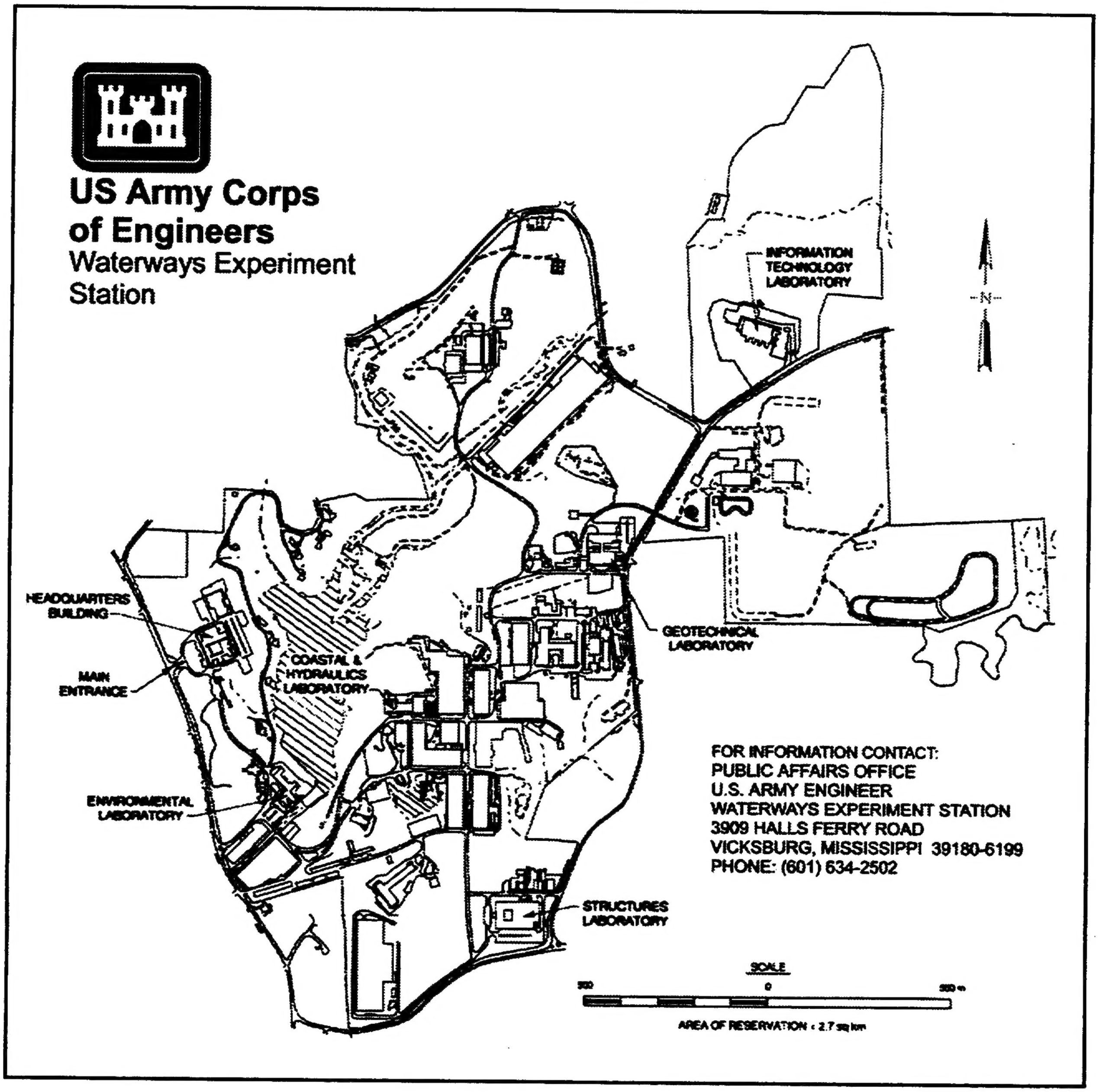

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Preface

The investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers, on 1 April 1991 at the request of the U.S. Army Engineer District, Pittsburgh.

The studies were conducted in the Hydraulics Laboratory (HL) of the U.S. Army Engineer Waterways Experiment Station (WES) during the period October 1994 to July 1996 under the direction of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; and G. A. Pickering and P. Combs, former and present Chiefs, Hydraulic Structures Division (HSD), HL. The experiments were conducted by Mrs. D.R. Cooper, Mr. R. Bryant, Jr., and Mr. E. L. Jefferson of the Spillways and Channels Branch, HSD, under the direct supervision of Mr. N. R. Oswalt and Mr. B. P. Fletcher, former and present Chiefs of the Spillways and Channels Branch. This report was prepared by Mrs. Cooper.

During the course of the investigation Messrs. W. Leput and R. Povirk of the Pittsburgh District visited WES to discuss investigation results and correlate these results with current design studies.

Mr. Melvin Bolden, Directorate of Public Works (DPW), WES, constructed the spillway, gates, and lock wall. The following DPW craftsmen molded river contours in the model: Messrs. Dan Barnes, Dennis Beausoliel, Charles Brown, Herman Brown, James Carpenter, Kenneth Chiplin, Clarence Drayton, Vincent Durman, Carl Gaston, Avery Harris, Donald Harris, Frank James, William Kelly, Joe Knox, Gene Logan, Bennie Neal, Charles Stamps, Arnold Taylor, Willie Thomas, Stacey Washington, and Charles Wilson.

During publication of this report, Dr. Robert W. Whalin was Director of WES. COL Bruce K. Howard, EN, was Commander.

1 Introduction

The Prototype

This report describes model experiments and results for a section of the Monongahela Dam 4 spillway project. Monongahela Dam 4 is located on the Monongahela River 34.1 km (21.2 miles) upstream of the confluence of the Ohio, Allegheny, and Monongahela Rivers, in the city of Charleroi, PA (Figure 1). The existing dam maintains the navigation pool between the Dam 4 and Dam 5 locks and dams (L&D). Normal upper pool elevation for Monongahela 4 is presently at el 743.5.[1] The minimum tailwater is presently at el 726.9.

The existing spillway section of Dam 4 consists of a gated crest (el 724.0) located within the main channel of the waterway. Energy is dissipated on a horizontal apron with baffle blocks terminated by an end sill. The U.S. Army Engineer District, Pittsburgh, developed a "two-for-three" plan for renovating locks and dams on the lower Monongahela River that would save the cost of having to reconstruct L&D 3 and reduce transportation costs by eliminating bottlenecks caused by the small locks at L&D's 3 and 4 and by reducing one lockage cycle. The plan calls for building a new gated dam at the current L&D 2, eliminating L&D 3, and replacing the locks at L&D 4 with new, larger locks. The change would also mean Pool 2 would be raised by about 1.5 m (5 ft) and the current Pool 3 would be lowered by about 1.0 m (3.2 ft) (lowering the tailwater for L&D 4 by 1.0 m (3.2 ft)). Normal and minimum tailwater curves for present and future conditions are included in Appendix A (page A2).

The dam consists of a navigable gated structure with three radial tainter gates and two piggyback gates as shown in Plates 1-3. The original derrick stone placed below the structure has experienced significant scour at one location (Appendix A, page A3). The future lower tailwater may result in more severe scour unless the condition is remedied. Additionally, a scour hole has developed in the streambed at one location upstream of the dam.

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[1] All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD). To convert them to meters, multiply by 0.3048.

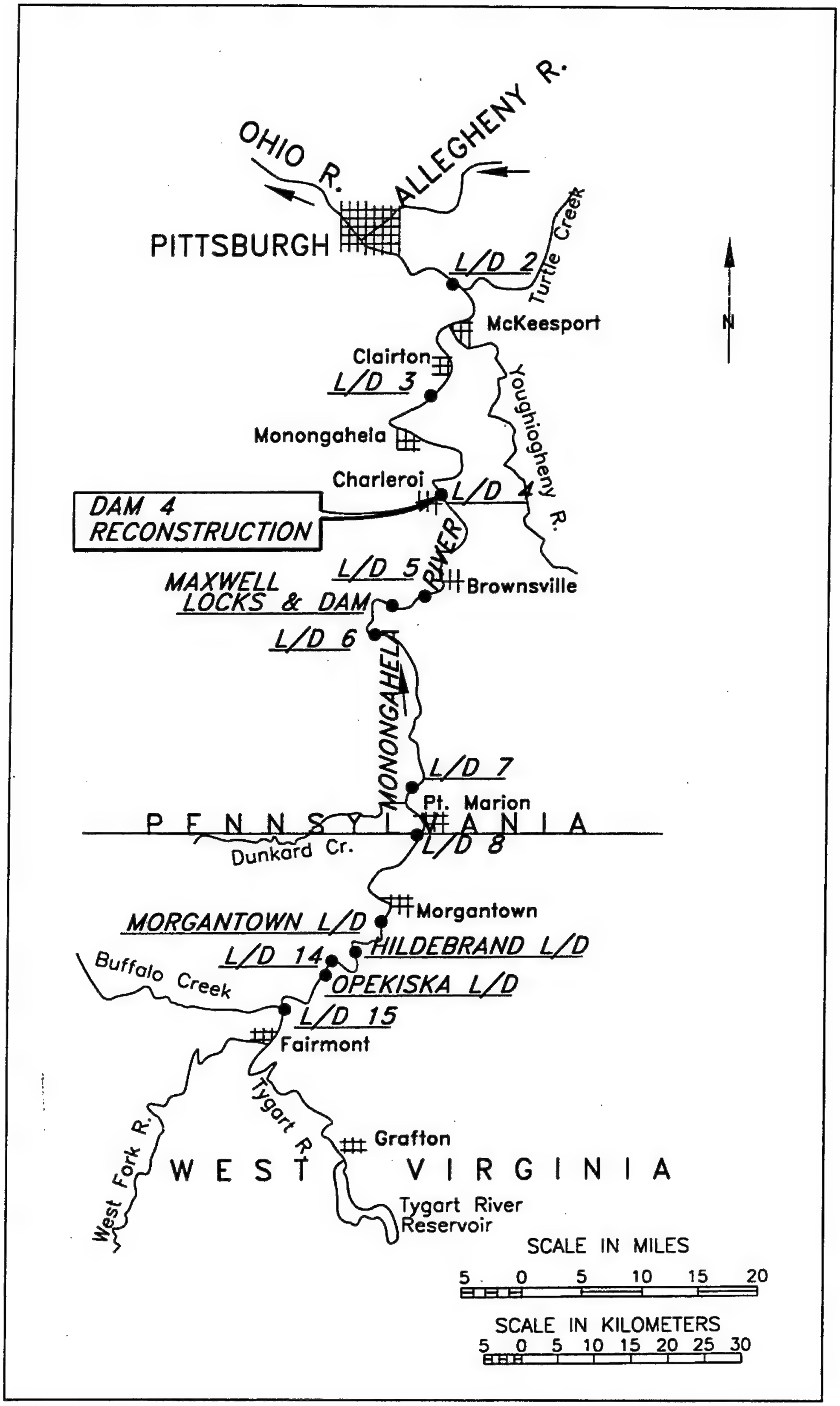


Figure 1. Location map

Appendix A
Model Testing Schedule Provided by the Pittsburgh District

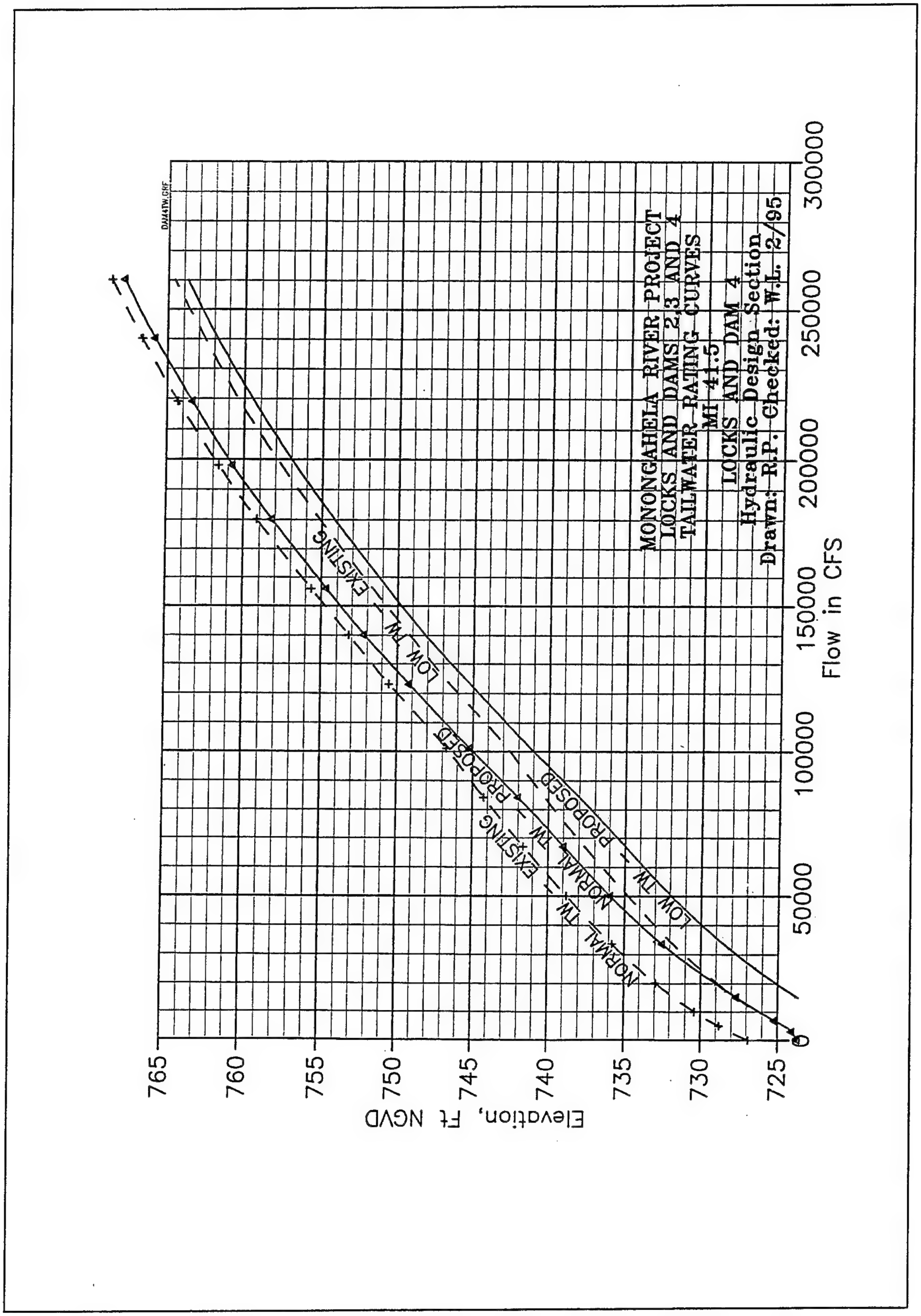


Figure A1. Tailwater rating curve

DISPOSITION FORM

For use of this form, see AR 340-15; the proponent agency is TAGO.

REFERENCE OR OFFICE SYMBOL	SUBJECT
CEORP-OR-W	Divers Inspection at Lock No. 4 Mon. River (cont.)

TO Page 3 FROM DATE 3 Jun 87 CMT 1

BAFFLES and CUT-OFF WALL below DAM

tops of baffles are broken off
Dimension shown is portion remaining.

Beginning at the Lock side of the Dam (see drawing No.3), baffles No.1 and 2 are intact.

From Nos. 3 thru 11 there is approx. 24 inches that has been broken off of the top.

Baffles No. 12 thru 19 have approx. 26 inches broken off of the top.

Nos. 20 thru 24 there is approx. 36 inches missing from the top.

Nos. 25 thru 27 have approx. 28 inches broken off of the top.

No. 28 is intact.

Nos. 29 and 30 are missing 24 inches from the top.

No. 31 iis intact.

Nos. 32 and 33 are missing approx. 24 inches from the top.

No. 34 is missing completely.

Nos. 35 and 36 are missing approx. 24 inches from the top.

Nos. 37 thru 39 are intact.

Nos. 40 and 41 are missing approx. 24 inches off of the top.

Nos. 42 thru 45 are intact.

end sill is in good shape
Cof on piling is o.k.

There is scour between baffles Nos. 17 and 18 that is approx. 2 ft. deep in the middle and tapers off to zero. This scour shows some undercutting of No. 17 baffle.

There is some washout and undercutting present with baffle No. 44 with reinforcing rod being exposed in places.

There is undercutting of the abutment (see drawing No. 3) of approx. 1 ft. that extends for about 5 feet in length.

The derrick stone protection beyond the cut-off wall has been washed outin various depths for the length of the dam (see drawing No. 1). It has also been washed out in front of the New River Wall, the most severe being on the weir side (see drawing No. 1).

There is a noticable gouge beyond the cut-off wall in front of pier No. 3 (see drawing No.2). It varies in depth from approx. 18 ft. to 24 ft. there is sheet piling exposed at the cut-off wall. This gouge is approx. 20 ft. wide and 18 ft. long.

DA FORM 2496 PREVIOUS EDITIONS WILL BE USED ☆ U.S. Government Printing Office: 1983—406-842

DAM 4 SECTION MODEL, EXISTING CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
TESTS TO CHARACTERIZE FLOW CONDITION
AND DETERMINE PROBABLE CAUSE OF DOWNSTREAM RIPRAP FAILURE

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
1	730.3*	743.5	26,500	2	2	4	2	2	17,200
2	735.8*	743.5	55,500	6	6	8	6	6	34,400
3	738.4*	743.5	70,700	10	10	12	10	10	44,200
4	739.8*	743.5	80,400	12	12	F	12	12	50,300
5	740.9*	743.5±	87,600	F	F	F	F	F	52,500
6	746.5*	748.5±	123,000	F	F	F	F	F	72,600

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks+esp. + fixed weir		Q gates		
1	Typical rising river	130	+	4@ 4,600 + 1@ 8,000	=	26,500
2	Typical rising river	130	+	4@ 10,500 + 1@ 13,400	=	55,500
3	Typical rising river	130	+	4@ 13,200 + 1@ 17,800	=	70,700
4	Typical rising river	130	+	4@ 15,000 + 1@ 20,300	=	80,400
5	Loss of pool	130	+	5@ 17,500	=	87,600
6	5-Year flow	2000	+	5@ 24,200	=	123,000

Procedure:

1. Run Tests 1-6 with all riprap downstream, including base underlaying armor layer as well as downstream stream bed. This will show whether protection would fail if a suitable filter and downstream toe had been provided.

2. If above runs do not produce a failure, rerun Tests 1-6 with transition filter material represented by coarse sand and original bed by fine sand. This will indicate whether washout of supporting bed or toe material caused or contributed to the failure.

Draft Rev. R.P. 7/12/95

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
ALL RIPRAP (ORIGINAL SPEC) IN MODEL
TOP TWO FEET OF END SILL REMOVED
TESTS TO CHARACTERIZE FLOW CONDITION
AND INITIALLY EVALUATE STABILITY OF DOWNSTREAM SCOUR PROTECTION

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
1	726.8*	743.5	26,400	2	2	4	2	2	17,200
2	733.5*	743.5	58,300	6	6	8	6	6	35,900
3	737.1*	743.5	79,600	10	10	12	10	10	48,800
4	739.0*	743.5	89,300	12	12	F	12	12	54,900
5	740.3*	743.5±	97,000	F	F	F	F	F	58,200
6	745.2*	748.0±	123,000	F	F	F	F	F	73,800

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
1	Typical rising river	0	+	4@ 4,600 + 1@ 8,000	=	26,400
2	Typical rising river	0	+	4@ 11,200 + 1@ 13,500	=	58,300
3	Typical rising river	0	+	4@ 15,400 + 1@ 18,000	=	79,600
4	Typical rising river	0	+	4@ 17,200 + 1@ 20,500	=	89,300
5	Loss of pool	0	+	5@ 19,400	=	97,000
6	5-Year flow	0	+	5@ 24,600	=	123,000

Procedure:

1. Run Tests 1-6 with original riprap downstream and top two feet of the end sill removed. If the riprap remains stable, it will indicate removal of a portion of the end sill would be beneficial.

Draft R.P. 8/05/95

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
8.5' LAYER OF D50=3.32' RIPRAP (EM SPEC) IN MODEL
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
TESTS TO DETERMINE WHETHER MAXIMUM PRACTICAL RIPRAP WILL BE ADEQUATE
WITHOUT MODIFICATIONS TO STILLING BASIN OR END SILL

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
1	723.7*	743.5	4,600	0	0	2	0	0	4,600
2	726.8*	743.5	26,400	2	2	4	2	2	17,200
3	733.5*	743.5	58,300	6	6	8	6	6	35,900
4	737.1*	743.5	79,600	10	10	12	10	10	48,800
5	739.0*	743.5	89,300	12	12	F	12	12	54,900
6	745.2*	748.0±	123,000	F	F	F	F	F	73,800

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
1	Low flow	0		1@ 4,600	=	4,600
2	Typical rising river	0	+	4@ 4,600 + 1@ 8,000	=	26,400
3	Typical rising river	0	+	4@ 11,200 + 1@ 13,500	=	58,300
4	Typical rising river	0	+	4@ 15,400 + 1@ 18,000	=	79,600
5	Typical rising river	0	+	4@ 17,200 + 1@ 20,500	=	89,300
6	5-Year flow	0	+	5@ 24,600	=	123,000

Procedure:

1. Run Tests 1-6 with 8.5-foot layer of EM-type riprap, with no modification to stilling basin or end sill. If the riprap remains stable, collect velocities downstream as shown on attached sketch.

Draft R.P. 8/28/95

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
8.5' LAYER OF D50=3.32' RIPRAP (EM SPEC) IN MODEL
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
TESTS TO DETERMINE WHETHER MAXIMUM PRACTICAL RIPRAP WILL BE ADEQUATE
WITHOUT MODIFICATIONS TO STILLING BASIN OR END SILL
ADDITIONAL TESTS

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL
7	730.6*	743.5	43,200	4	4	6	4	4	27,200
8	735.5*	743.5	70,000	8	8	10	8	8	43,000
9	740.3*	743.5±	97,000	F	F	F	F	F	58,200
10	723.7*	743.5	11,200	0	0	6	0	0	11,200
11	727.0	743.5	13,500	0	0	8	0	0	13,500
12	729.0	743.5	20,500	0	0	F	0	0	20,500

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
7	Typical rising river	0	+	4@ 8,000 + 1@ 11,200	=	43,20
8	Typical rising river	0	+	4@ 13,500 + 1@ 16,000	=	70,00
9	Loss of pool	0	+	5@ 19,400	=	97,00
10	Debris underflow	0	+	1@ 11,200	=	11,20
11	Debris underflow	0	+	1@ 13,500	=	13,50
12	Debris underflow	0	+	1@ 20,500	=	20,50

Procedure:

1. Run Tests 7-12 with 8.5-foot layer of EM-type riprap for two hour each, with no modification to stilling basin or end sill.

Draft R.P. 9/26/95

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
8.5' LAYER OF D50=3.32' RIPRAP (EM SPEC) IN MODEL
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
TESTS TO DETERMINE WHETHER MAXIMUM PRACTICAL RIPRAP WILL BE ADEQUATE
WITHOUT MODIFICATIONS TO STILLING BASIN OR END SILL
ADDITIONAL TESTS (ONE GATE OUT OF SERVICE)

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
13	728.9*	743.5	35,200	4	4	0	6	4	19,200
14	733.1*	743.5	56,500	8	10	0	8	8	29,500
15	736.3*	743.5±	74,500	12	12	0	F	12	38,500

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
13	Typical rising river	0	+	3@ 8,000 + 1@ 11,200	=	35,200
14	Typical rising river	0	+	3@ 13,500 + 1@ 16,000	=	56,500
15	Typical rising river	0	+	3@ 18,000 + 1@ 20,500	=	74,500

Procedure:

1. Run Tests 13-15 with 8.5-foot layer of EM-type riprap for two hours each, with no modification to stilling basin or end sill.

Draft R.P. 10/5/95

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN LEFT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN RIGHT BAY
PLAN 3 MODIFIED - 60' STILLING BASIN EXTENSION, RIPRAP D50=3.3', 3144#
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
TESTS TO DETERMINE RIPRAP STABILITY
ADDITIONAL TESTS (TESTS 1-6 NO CHANGE)

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
7	730.6*	743.5	43,200	4	4	6	4	4	27,200
8	735.5*	743.5	69,600	8	8	10	8	8	42,600
9	740.3*	743.5±	97,000	F	F	F	F	F	58,200
10	723.7*	743.5	11,200	0	0	6	0	0	11,200
11	723.7*	743.5	13,500	0	0	8	0	0	13,500
11a	723.7	743.5	15,600	0	0	10	0	0	15,600
12	729.0	743.5	20,500	0	0	F	0	0	20,500
12a	723.7	743.5	20,500	0	0	F	0	0	20,500
13	728.9*	743.5	35,200	4	4	0	6	4	19,200
14	733.1*	743.5	56,100	8	10	0	8	8	29,100
15	736.3*	743.5±	74,500	12	12	0	F	12	38,500

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
7	Typical rising river	0	+	4@ 8,000 + 1@ 11,200	=	43,200
8	Typical rising river	0	+	4@ 13,500 + 1@ 15,600	=	69,600
9	Loss of pool	0	+	5@ 19,400	=	97,000
Debris underflow tests:						
10	min TW	0	+	1@ 11,200	=	11,200
11	min TW	0	+	1@ 13,500	=	13,500
11a	min TW (transient cond)	0	+	1@ 15,600	=	15,600
12	normal TW	0	+	1@ 20,500	=	20,500
12a	min TW (transient cond)	0	+	1@ 20,500	=	20,500
One gate out of service tests:						
13	Typical rising river	0	+	3@ 8,000 + 1@ 11,200	=	35,200
14	Typical rising river	0	+	3@ 13,500 + 1@ 15,600	=	56,100
15	Typical rising river	0	+	3@ 18,000 + 1@ 20,000	=	74,500

R.P. 3/14/96

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN RIGHT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN LEFT BAY
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
PLAN 3 MODIFIED - 60' STILLING BASIN EXTENSION, RIPRAP D50=3.3', 3144#
ABUTMENT PROTECTION INSTALLED ON LEFT SIDE OF MODEL
TESTS TO DETERMINE ADEQUACY OF PROTECTION PLAN
TESTS 1-6 (ALSO SEE ADDITIONAL TESTS 7-15)

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
1	723.7	743.5	4,600	0	0	2	0	0	4,600
2	726.8*	743.5	26,400	2	2	4	2	2	17,200
3	733.5*	743.5	58,300	6	6	8	6	6	35,900
4	737.1*	743.5	79,600	10	10	12	10	10	48,800
5	739.0*	743.5	89,300	12	12	F	12	12	54,900
6	745.2*	748.0±	123,000	F	F	F	F	F	73,800

* MIN TAILWATER CURVE   F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
1	Low flow	0		1@ 4,600	=	4,600
2	Typical rising river	0	+	4@ 4,600 + 1@ 8,000	=	26,400
3	Typical rising river	0	+	4@ 11,200 + 1@ 13,500	=	58,300
4	Typical rising river	0	+	4@ 15,400 + 1@ 18,000	=	79,600
5	Typical rising river	0	+	4@ 17,200 + 1@ 20,500	=	89,300
6	5-Year flow	0	+	5@ 24,600	=	123,000

R.P. 5/23/96

DAM 4 SECTION MODEL, PROPOSED CONDITIONS
SINGLE LEAF GATES INSTALLED IN RIGHT AND CENTER BAYS
DOUBLE LEAF GATE INSTALLED IN LEFT BAY
BROKEN BAFFLES AND ORIGINAL END SILL INSTALLED
PLAN 3 MODIFIED - 60' STILLING BASIN EXTENSION, RIPRAP D50=3.3', 3144#
ABUTMENT PROTECTION INSTALLED ON LEFT SIDE OF MODEL
TESTS TO DETERMINE ADEQUACY OF PROTECTION PLAN
ADDITIONAL TESTS

TEST NO.	TAIL-WATER	UPPER POOL	TOTAL Q	GATE #1	GATE #2	GATE #3	GATE #4	GATE #5	MODEL Q
7	730.6*	743.5	43,200	4	4	6	4	4	27,200
8	735.5*	743.5	69,600	8	8	10	8	8	42,600
9	740.3*	743.5±	97,000	F	F	F	F	F	58,200
10	723.7*	743.5	11,200	0	0	0	0	6	11,200
10x	723.7*	743.5	11,200	0	0	0	6	0	11,200
11	723.7*	743.5	13,500	0	0	0	0	8	13,500
11x	723.7*	743.5	13,500	0	0	0	8	0	13,500
11a	723.7	743.5	15,600	0	0	0	0	10	15,600
11ax	723.7	743.5	15,600	0	0	0	10	0	15,600
12	729.0	743.5	20,500	0	0	0	0	F	20,500
12a	723.7	743.5	20,500	0	0	0	0	F	20,500
12ax	723.7	743.5	20,500	0	0	0	F	0	20,500
13	728.9*	743.5	35,200	4	4	6	0	4	19,200
14	733.1*	743.5	56,100	8	8	10	0	8	29,100
15	736.3*	743.5±	74,500	12	12	F	0	12	38,500

* MIN TAILWATER CURVE F = OPEN FULL

Derivation:

Test No.	Test Description	Q locks + esplanade		Q gates		
7	Typical rising river	0	+	4@ 8,000 + 1@ 11,200	=	43,200
8	Typical rising river	0	+	4@ 13,500 + 1@ 15,600	=	69,600
9	Loss of pool	0	+	5@ 19,400	=	97,000
Debris underflow tests:						
10	min TW	0	+	1@ 11,200	=	11,200
11	min TW	0	+	1@ 13,500	=	13,500
11a	min TW (transient cond)	0	+	1@ 15,600	=	15,600
12	normal TW	0	+	1@ 20,500	=	20,500
12a	min TW (transient cond)	0	+	1@ 20,500	=	20,500
One gate out of service tests:						
13	Typical rising river	0	+	3@ 8,000 + 1@ 11,200	=	35,200
14	Typical rising river	0	+	3@ 13,500 + 1@ 15,600	=	56,100
15	Typical rising river	0	+	3@ 18,000 + 1@ 20,000	=	74,500

R.P. 5/23/96

MON RIVER L/D 4 SECTION MODEL

UPSTREAM SCOUR TEST FOR EXISTING CONDITIONS

MODEL DURATION (HOURS)	TOTAL FLOW (CFS)	MODEL FLOW (CFS)	TAILWATER ELEVATION (NGVD)	HEADWATER ELEVATION (NGVD)	GATE OPEN #1 (FT)	#2 (FT)
0.67	50,000	20,000	738.8	743.5	8	8
2.33	72,100	28,800	742.4	743.6±	Full	Full
2.67	84,000	33,400	744.3	745.5±	Full	Full
1.67	75,000	30,000	742.8	744.1±	Full	Full
2.17	60,000	24,000	740.4	743.5±	12	12
2.0	43,000	17,200	737.6	743.5	6	6

11.5 hrs total

R.P. Rev. 6/20/95

UPSTREAM SCOUR TEST FOR PROPOSED CONDITIONS

MODEL DURATION (HOURS)	TOTAL FLOW (CFS)	MODEL FLOW (CFS)	TAILWATER ELEVATION (NGVD)	HEADWATER ELEVATION (NGVD)	GATE OPEN #1 (FT)	#2 (FT)
0.67	50,000	20,000	736.3	743.5	6	6
2.33	72,100	28,800	739.0	743.5±	12	12
2.67	84,000	33,400	742.0	743.5±	Full	Full
1.67	75,000	30,000	740.4	743.5±	14	14
2.17	60,000	24,000	737.6	743.5	8	8
2.0	43,000	17,200	735.5	743.5	5	5

11.5 hrs total

Purpose and Scope of the Model Study

The spillway sectional model study was conducted to investigate the hydraulic performance of the structure under long-range operating conditions for controlled and uncontrolled flows. Specifically, the model study would provide the data necessary to evaluate and develop a satisfactory means of operating and protecting the structure from scour without creating adverse hydraulic conditions. The following information was obtained for the structure:

a. Flow characteristics and stilling basin performance with gates fully open (uncontrolled flow).

b. Flow characteristics and stilling basin performance with partial closure of the gates from the top of the structure (orifice flow under gates).

c. Relative degree of turbulence (as shown by dye) observed visually in the stilling basin and exit channel.

d. Requirements for scour protection downstream of the structure.

e. Discharge characteristics and coefficients with various operating scenarios, including ice underflow.

f. Upstream scour potential.

Presentation of Data

In the presentation of experimental results, the data are not always discussed in the chronological order in which the experiments were conducted on the model. Instead, as each element of the structure is considered, all experiments conducted thereon are discussed in detail. All model data are presented in terms of prototype equivalents. All experiments are discussed in Part 3 of this report.

2 The Model and Experiments Procedure

Description

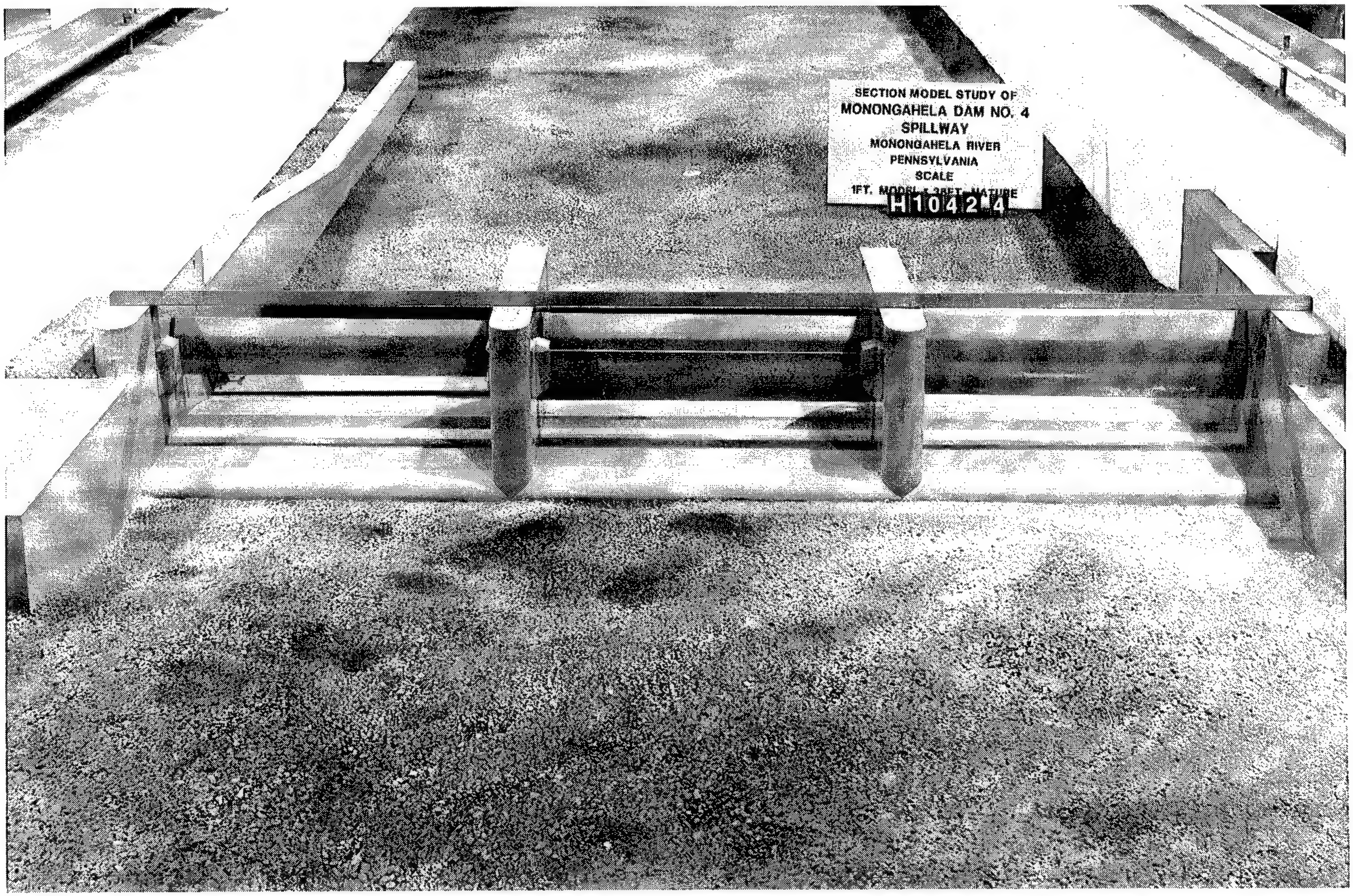
Initially the 1:36-scale section model (Figure 2, Plate 4) reproduced a 98.8-m- (324-ft-) wide middle section of the dam consisting of three broad-crested sills at el 724.0, one 25.6-m- (84-ft-) wide and 6.4-m- (21-ft-) high piggyback gate and two 25.6-m- (84-ft-) wide and 6.4-m- (21-ft-) high tainter gates (gate bays 2-4), four 3.0-m- (10-ft-) wide piers and the left abutment, a 19.2-m- (63-ft-) long stilling basin and basin elements, 190 m (620 ft) of the upstream approach channel, and 203 m (666 ft) of the exit channel. The initial model layout is referred to as configuration 1.

To examine the discharge characteristics and riprap requirements for the abutment end of the dam, the section model was modified (configuration 2) to reproduce a 98.8-m- (324-ft-) wide section of the dam consisting of three broad-crested sills at el 724.0, two 25.6-m- (84-ft-) wide and 6.4-m- (21-ft-) high tainter gates and one 25.6-m- (84-ft-) wide and 6.4-m- (21-ft-) high piggyback gate (gate bays 3-5), four 3.0-m- (10-ft-) wide piers and the left abutment, a 19.2-m- (63-ft-) long stilling basin and basin elements (Plate 5), 190 m (620 ft) of the upstream approach channel, and 203 m (666 ft) of the exit channel.

The weir section, piers, and tainter gates were constructed of metal. The stilling basin and basin elements were constructed of wood. The portions of the model representing the approach channel were molded in pea gravel and dusted with cement, and the exit channel was molded in sand and gravel.

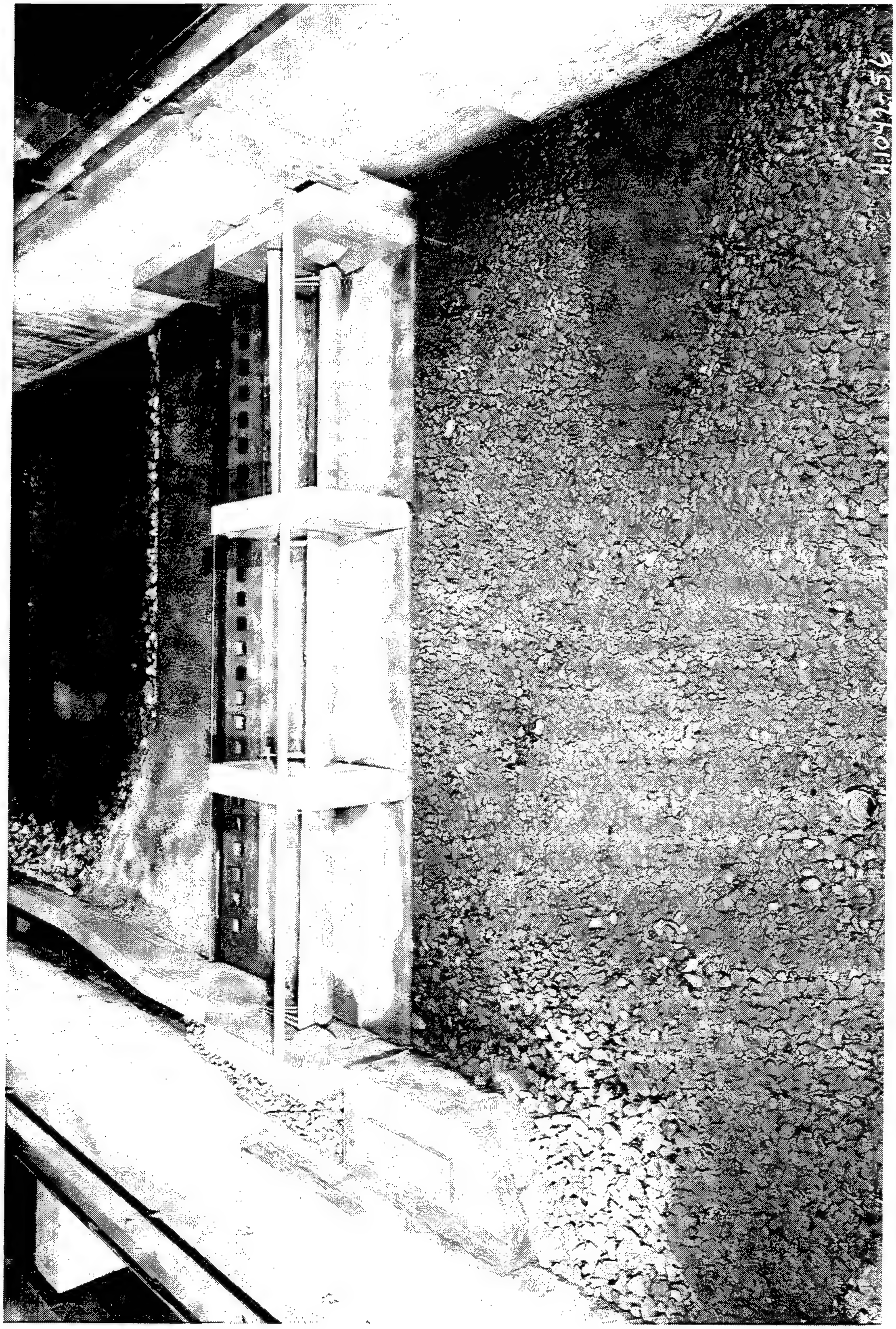
Appurtenances and Instrumentation

Water used in the operation of the model was supplied by pumps, and discharges were measured with venturi meters. The tailwater in the



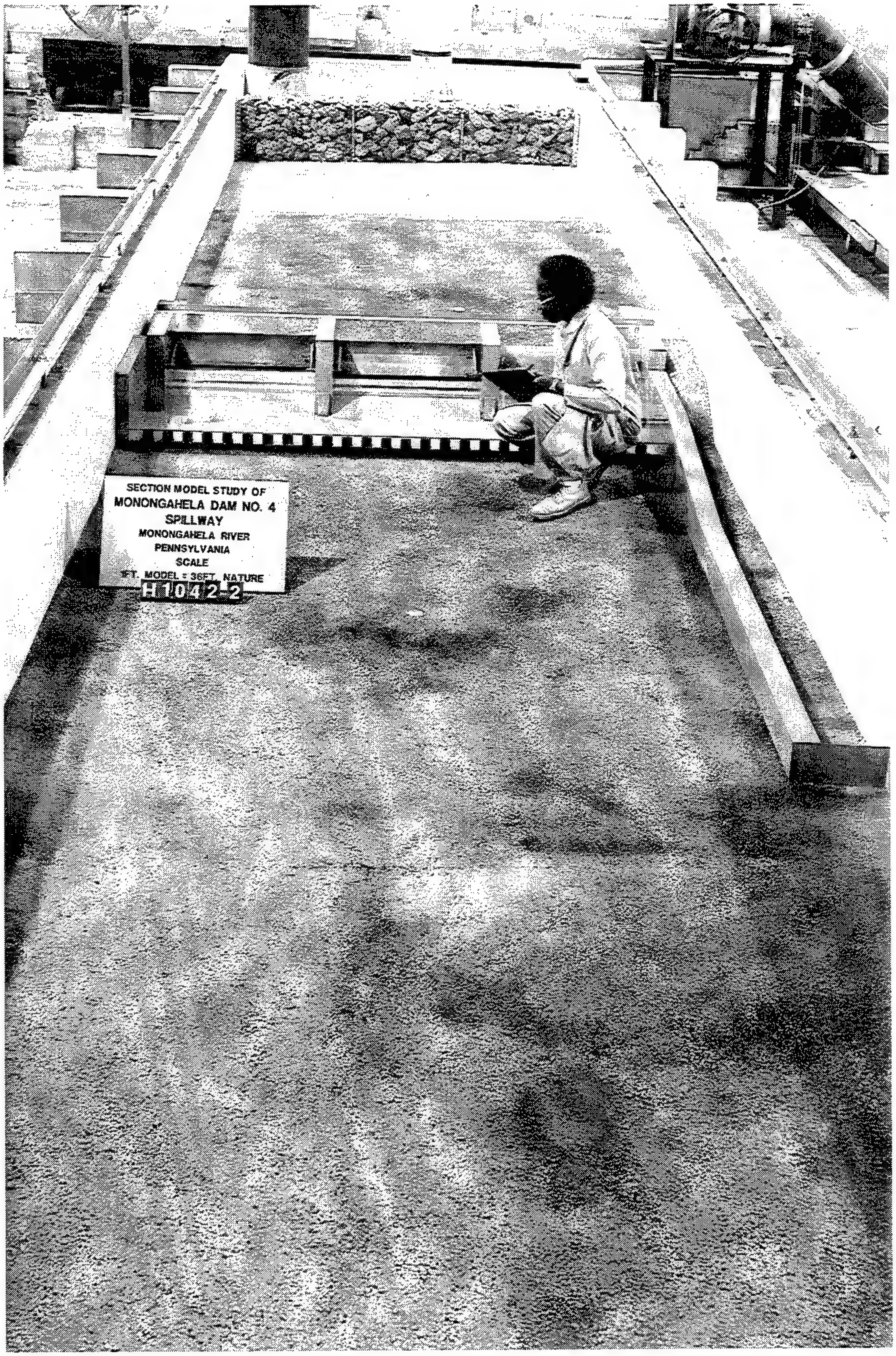
a. Close-up view looking downstream

Figure 2. 1:36-scale model (Sheet 1 of 4)



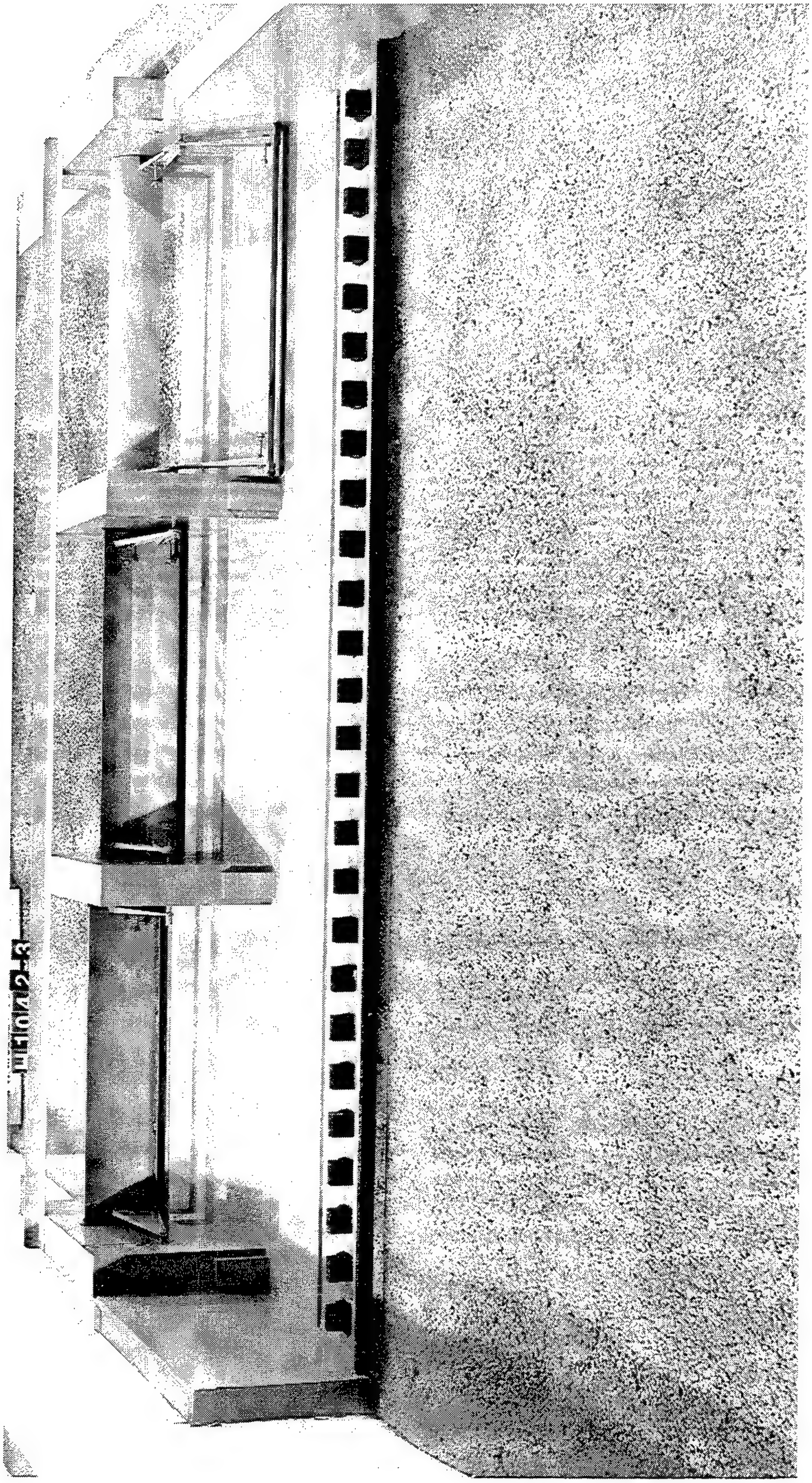
b. Looking downstream

Figure 2. (Sheet 2 of 4)



c. Looking upstream

Figure 2. (Sheet 3 of 4)



d. Close-up view looking upstream

Figure 2. (Sheet 4 of 4)

downstream end of the model was controlled by an adjustable tailgate. Steel rails set to grade provided reference planes. Water-surface elevations were obtained with point gages. Velocities were measured with a Nixon 402 digital flowmeter.

Scale Relations

The accepted equations of similitude, based upon the Froudian relations, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. General relations for the transference of model data to prototype equivalents are presented in the following tabulation:

Dimension	Ratio	Scale Relations Model:Prototype
Length	$L_r = L$	1:36
Area	$A_r = L_r^2$	1:1,296
Velocity	$V_r = L_r^{1/2}$	1:6
Discharge	$Q_r = L_r^{5/2}$	1:7,776
Time	$T_r = L_r^{1/2}$	1:6

Because of the nature of the phenomena involved, certain model data can be accepted quantitatively, while other data, such as scour patterns, are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and resistance to displacement of riprap material can be transferred quantitatively from model to prototype by means of these scale relations. Evidence of scour of the model bed, however, is to be considered only as qualitatively reliable since it has not yet been found possible to reproduce quantitatively in a model the relative extent of erosion that occurs in the prototype with cohesive or noncohesive fine-grained bed material. Data on scour tendencies provided a basis for determination of the relative effectiveness of the different designs and indicated the areas most subject to degradation and deposition.

Experiment Procedure

Experiments were conducted in the model to observe the flow patterns, velocities, discharges, and overall hydraulic performance of the spillway, stilling basin, and exit channel. A typical experiment consisted of setting a discharge and tailwater elevation, and recording the stable pool elevation. Hydraulic performance was documented for each flow condition. Tailwater

elevations were measured at a point 141.4 m (464 ft) downstream from the dam face (sta 3+99.5B) with the tailwaters set according to the curves provided by the Pittsburgh District shown in Appendix A, page A2. During these experiments, when only one gate was operated, there was no leakage through the other gate bays.

Riprap stability experiments were conducted using the model experiment schedules provided by the Pittsburgh District in Appendix A (pages A4-A11).

3 Experiments and Results

Discharge Characteristics

Flow conditions

Experiments to determine the discharge characteristics of the spillway with the broad-crested weir were conducted for each of the following flow conditions:

a. Free uncontrolled flow. Gate fully open; upper pool unaffected by the tailwater.

b. Submerged uncontrolled flow. Gate fully open; upper pool controlled by the submergence effect of the tailwater.

c. Free controlled flow. Gate partially open; upper pool unaffected by the tailwater; controlled by the particular gate opening with flow under the gate.

d. Submerged controlled flow. Gate partially open; upper pool controlled by both the submergence effect of the tailwater and the gate opening with flow under the gate.

Description of experiments

Free uncontrolled and controlled flow characteristics for a single gate were determined by introducing various constant discharges into the model and observing the corresponding upper pool elevation for several tailwater elevations. Sufficient time was allowed for stabilization of the upstream flow conditions. Upper pool elevations were measured at a point 125.6 m (412 ft) upstream from the dam face (sta 4+76.5A). Total head on the crest H or total head on the gate H_g was computed by adding mean velocity head to the upper pool. Tailwater elevations were measured at a point 141.4 m (464 ft) downstream from the dam face (sta 3+99.5B). During these experiments, the left and right gates were closed and sealed to prevent leakage.

Submerged flow discharge characteristics for both controlled and uncontrolled flows were determined by introducing several constant discharges into the model and varying the tailwater by small increments for each from an elevation at which no interference in spillway flow was evident to an elevation at which the flow condition became submerged. The elevation of the upper pool was noted at each of the tailwater elevations.

Weir capacity

The head-discharge rating curves for free uncontrolled flow are presented in Plate 6. The equation for the curve is the best empirical fit of the free flow data by the method of least squares.

Calibration data

The basic calibration data, presented in Plates 7-11 and Tables 1-5, show the upper pool elevation corresponding to a particular elevation of the tailwater for a given discharge observed with the section model (crest el 724.0).

Uncontrolled flow data for the structure are shown in Plate 7. The data for each of the various discharges shown in this plate illustrate the following:

a. The relation between the elevation of the upper pool and the tailwater elevation in the exit channel.

b. The range of tailwater elevations at which the upper pool elevation is constant.

c. The range of tailwater elevations at which the upper pool elevation is controlled by the submergence effect of the tailwater, i.e., the range of submerged uncontrolled flow.

Free and submerged controlled flow data are shown in Plates 8-11. The data for each of the various discharges shown in these plates illustrate the following:

a. The relation between the elevation of the upper pool and the tailwater elevation in the exit channel for a particular gate opening.

b. The range of tailwater elevations at which the upper pool elevation is constant, i.e., the range at which the flow is free from the submergence effects of the tailwater, and either free uncontrolled or free controlled flow exists depending upon the discharge, gate opening, and head on the weir.

c. The range of tailwater elevations at which the upper pool elevation is controlled by the submergence effect of the tailwater, and the range at

which the flow is controlled by both the submergence effect of the tailwater and the particular gate opening.

Discharge-head relations and data for free flow conditions are presented in Plate 6. This plot represents partial closure of the gates from the top of the structure (orifice flow under gates). Tailwater effect on discharge for uncontrolled flow and controlled flow and normal pool el 743.5 are presented in Plate 12 and Table 5. The data in Table 5 represent measured pool elevations.

Analyses of data

The flow conditions and equations used to satisfy the experimental data are as follows:

a. Free uncontrolled flow:

$$Q = CLH^{3/2} \tag{1}$$

where C ranges from 2.70 to 2.83 as shown in Table 1.

b. Submerged uncontrolled flow:

$$Q = C_s Lh\sqrt{2g\Delta H} \tag{2}$$

where C_s ranges from 0.85 to 1.01 as shown in Table 2.

c. Free controlled flow:

$$Q = C_g LG_o\sqrt{2gH_g} \tag{3}$$

where C_g ranges from 0.600 to 0.715 as shown in Table 3.

d. Submerged controlled flow:

$$Q = C_{g_s} Lh\sqrt{2g\Delta H} \tag{4}$$

where C_{g_s} ranges from 0.27 to 1.66 as shown in Table 4.

Symbols used in these equations are defined as follows:

Q = discharge per bay, cfs

C = discharge coefficient for free uncontrolled flow

L = net length of spillway crest, ft

H = total head on weir (including velocity head), ft

C_s = discharge coefficient for submerged uncontrolled flow

h = tailwater elevation referred to weir crest, ft

g = acceleration due to gravity, ft/sec^2

ΔH = Differential between gross head on spillway weir and depth of tailwater referenced to the weir $(H - h)$, ft

C_g = discharge coefficient for free controlled flow

G_o = gate opening, ft

H_g = total head on gate $(H - G_o/2)$, ft

C_{g_s} = discharge coefficient for submerged controlled flow

Quantities determined from the experimental data were substituted in the equations, and the discharge coefficients for the respective flow conditions were computed. It was beyond the scope of the model study to determine generalized functions for the coefficients. Analytical evaluations of the experimental data were conducted to assure that reasonable discharge coefficients were determined. Free and submerged discharge coefficients calculated from the experimental results from this model study were superimposed on Hydraulic Design Criteria[1] (HDC) charts of established Corps discharge coefficients. While the experimental discharge coefficients did not match the HDC coefficients, it was determined that approach depth in the model was very shallow compared to the large depth of approach flow used for determination of the HDC coefficients.

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[1] U.S. Army Corps of Engineers. "Hydraulic design criteria," prepared for Headquarters, U.S. Army Corps of Engineers, by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, issued serially since 1952.

Riprap Requirements

Existing conditions experiments, Configuration 2

To simulate true prototype existing conditions, the baffles in the stilling basin were removed or broken to simulate missing and/or broken baffles based on a diver's inspection report provided by the Pittsburgh District (Appendix A, page A3). One piggyback and two radial tainter gates (gate bays 3-5) were investigated. Initially, an 8.8-m- (29-ft-) thick rock ledge simulating 0.9-m (3-ft) derrick stone was placed for 6.0 m (20 ft) immediately downstream of the end sill followed by a 9.1-m- (30-ft-) long, 1V on 2H, and a 29.6-m- (97-ft-) long, 1V on 13.85H derrick stone wedge as shown in Figures 3 and 4 and Plates 13 and 14. This was designated the type 1 (existing) stone protection. Gradation curves for the derrick stone used in the model are shown in Plate 15. Each of the steady-state conditions shown on page A4 (experiments 1-6) was run for 6 hours (prototype). The derrick stone was displaced in several locations downstream of the dam during experiments 1 and 4 indicating that the original design and 1967 reconstruction of the dam were inadequate.

Cursory experiments were conducted for proposed future pool conditions with the existing derrick stone protection to determine the impact of modifications to the stilling basin on the stability of the downstream protection. The top 0.6 m (2 ft) of the end sill was removed and the steady-state conditions shown on page A5 (experiments 1-6) were run for 6 hours (prototype). The stone failed again during experiments 1 and 4.

Proposed future conditions experiments, Configuration 1

The top 0.6 m (2 ft) of the end sill was reattached and a 2.6-m- (8.5-ft-) thick blanket simulating protective stone with a D_{50min} of 1 m (3.3 ft) (Class A) was installed in the model immediately downstream of the end sill as shown in Figure 5 and Plates 16 and 17. Gradation curves for the riprap used in the model are shown in Plate 18. The 2.6-m- (8.5-ft-) thick blanket simulating protective stone with a D_{50min} of 1 m (3.3 ft) was placed at 1V on 3H for 26.5 m (87 ft) downstream of the end sill as shown in Figure 5 and Plates 16 and 17. The riprap sloped from el 720.0 to el 691.0 (the top of soft rock). This was designated the type 2 design riprap protection plan. Each of the steady-state conditions shown on pages A6-A8 was run for 12 hours (prototype) for a factor of safety. The significance of each experiment with respect to the prototype can be found in the District-furnished material included in Appendix A. The riprap failed at the toe during single gate operation at gate openings of 1.8 m (6 ft), 2.4 m (8 ft), and fully open. Flow conditions for each experiment are shown in Photos 1-15. Results of riprap stability experiments are presented in Table 6. Increasing stone size at the toe of the slope did not eliminate the failures. Additional single gate experiments resulted in

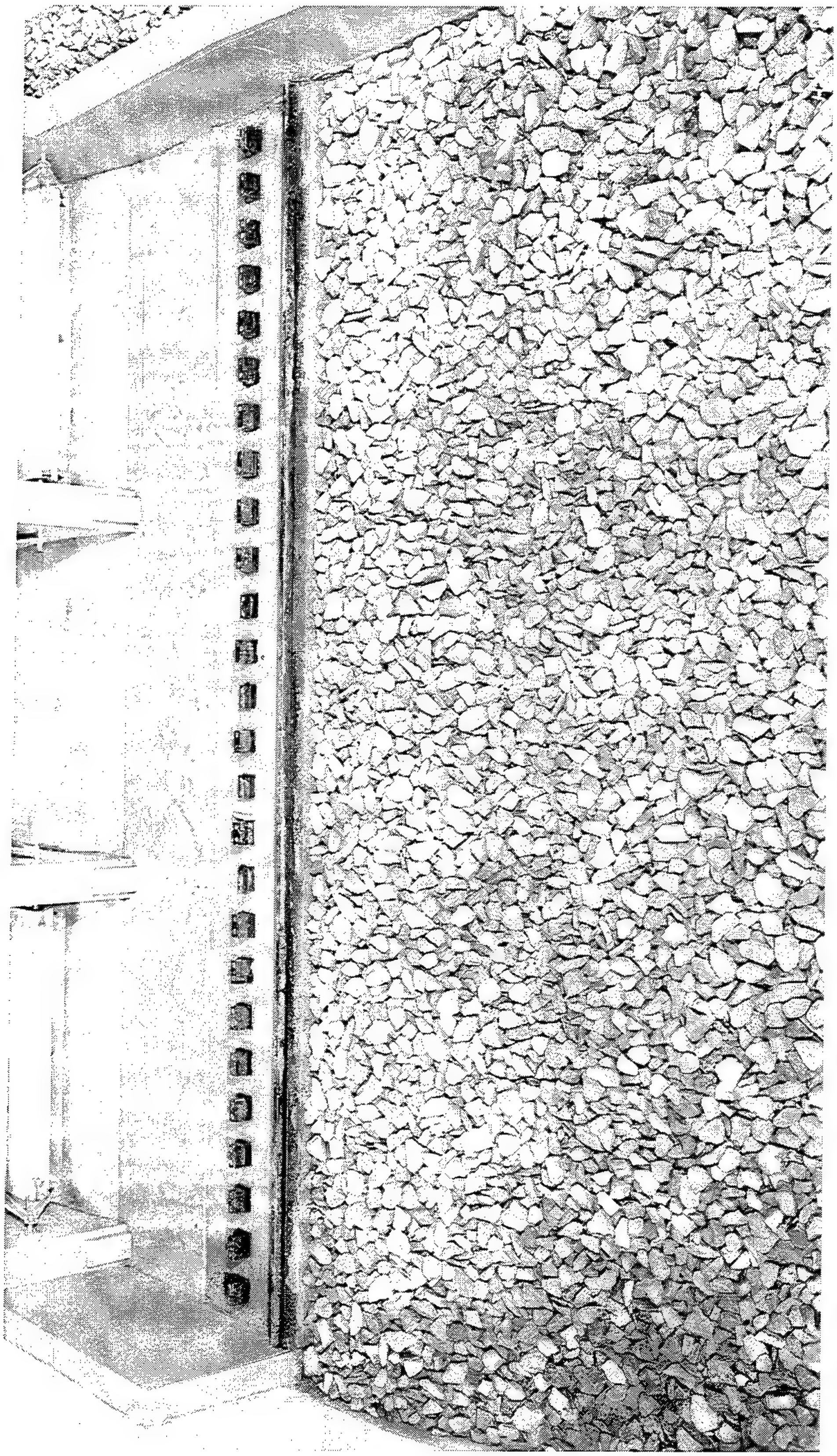

Figure 3. 1:36-scale model stilling basin with broken baffles, looking upstream

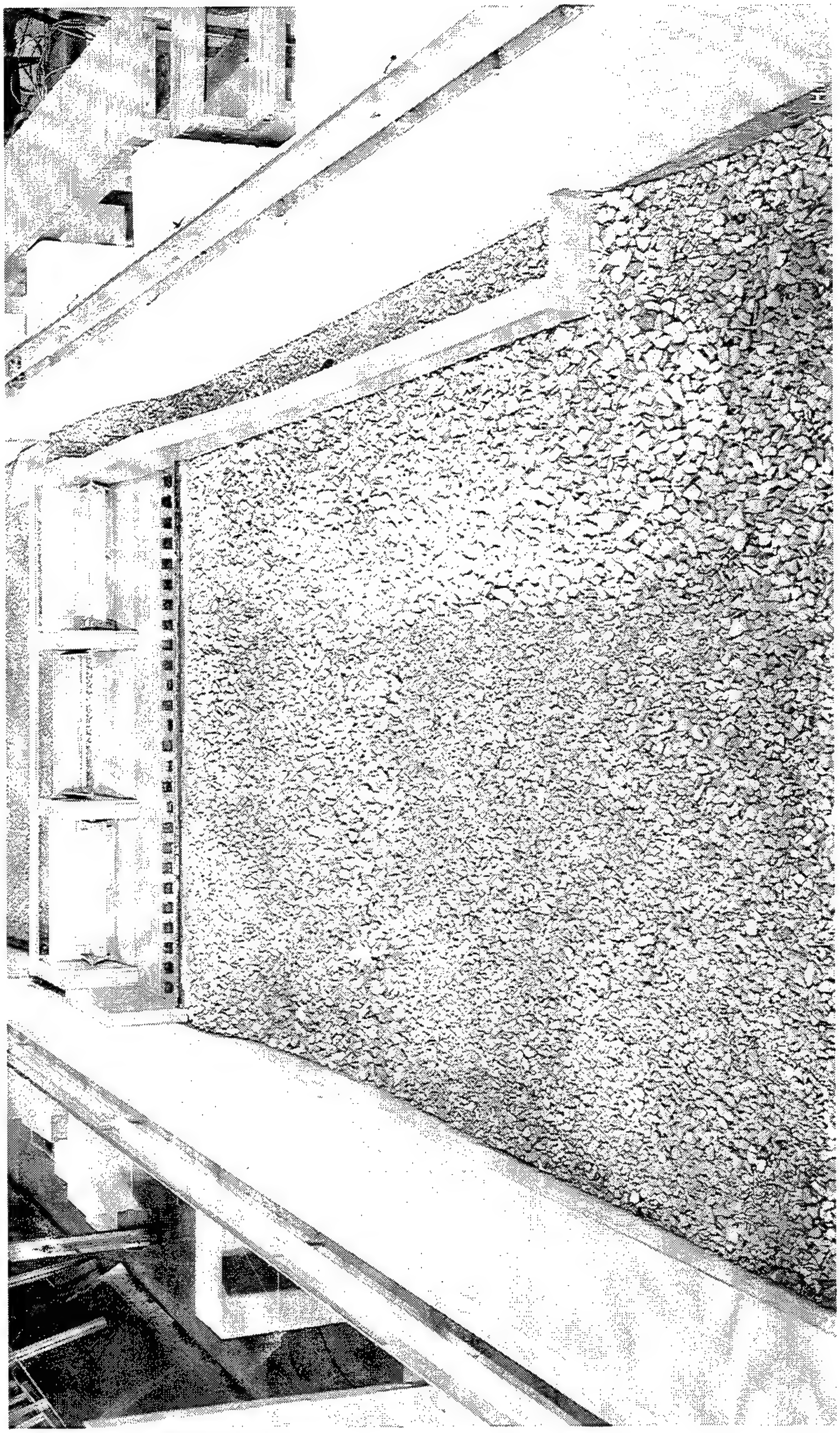

Figure 4. Type 1 (existing) derrick stone, looking upstream

Figure 5. Type 2 riprap protection, Configuration 1, looking upstream

establishment of elevations 730.0, 730.0 and 731.0, respectively, as safe tailwater limits for 1.8-, 2.4-, and 3-m (6-, 8-, and 10-ft) gate openings.

The stilling basin apron was artificially extended at el 716.0 for 9.8 m (32 ft). A grouted rock apron was placed in the model for 9.8 m (32 ft) followed by a 15.5-m- (51-ft-) long, 1V on 3H blanket simulating protective stone with a D_{50min} of 1 m (3.3 ft) (Class A). The 1V on 3H blanket of stone sloped from el 715.0 to el 698.0. A 4.6-m- (15-ft-) long and 2.1-m- (7-ft-) thick horizontal ledge followed by a 2.1-m- (7-ft-) long, 1V on 1H wedge of uniformly graded 1.2-m- (4-ft-) diameter protective stone (Class B) provided added stability at the toe of the riprap. The jet exiting the original 19.2-m- (63-ft-) long stilling basin impacted too close to the end of the apron extension with flow plunging off the rock apron into the sloping downstream riprap protection. It was determined that the rock apron was not long enough to allow the exiting jet to be turned horizontally.

The stilling basin apron was artificially extended at el 716.0 for 18.3 m (60 ft). The downstream riprap protection remained the same (Plates 19 and 20). Gradation curves for the riprap used in the model are shown in Plates 18 and 21. This was designated the type 3 design riprap/rock apron protection plan. Each of the steady-state conditions shown on pages A6 (experiments 1-6) and A9 (experiments 7-15) was run for 24 hours (prototype) for a factor of safety. The riprap remained stable throughout the range of flows investigated in the model. Results of riprap stability experiments are presented in Table 7. Bottom velocities were measured to document flow conditions over the riprap and are shown in Plates 22-32. The experiment schedule satisfies the requirements of Engineer Manual (EM) 1110-2-1605[1] for investigation of half-open and fully open gates at normal pool with minimum tailwater.

Proposed future conditions experiments, configuration 2

Although the type 2 riprap protection plan failed with single gate openings with low tailwater under Configuration 1, the Pittsburgh District wanted to determine whether the type 2 plan would be stable under ordinary operating conditions in the abutment area. Thus limited experimentation with Configuration 2 was done. Two radial tainter and one piggyback gates (gate bays 3-5) were investigated. A 2.6-m- (8.5-ft-) thick blanket simulating protective stone with a D_{50min} of 1 m (3.3 ft) (Class A) was installed in the model immediately downstream of the end sill as shown in Plate 33. A transition of riprap along the abutment was placed on a 1V on 2H slope from the abutment down to el 691.0 as shown in Plate 33. Gradation curves for the riprap used in the model are shown in Plate 18. Each of the following steady-state conditions, which represent prototype conditions with one of the five gates inoperable, was run as indicated (pool el was 743.5 for all runs):

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[1] Headquarters, U.S. Army Corps of Engineers. (1987(12 May)). "Hydraulic design of navigation dams," EM 1110-2-1605, U.S. Government Printing Office, Washington, DC.

Tailwater El	Opening, m (ft) Gate			Discharge cu m/sec (cfs)	Time, prototype hours
	3	4	5		
737.5	Full	Full	Full	1,722 (61,500)	9
734.0	3 (10)	3 (10)	3 (10)	1,302 (46,500)	12
732.8	2.4 (8)	2.4 (8)	2.4 (8)	1,134 (40,500)	12

The riprap failed at the toe with all three conditions. Experiments conducted after replacing missing and repairing damaged baffles indicated such repairs did not prevent the riprap protection failures.

The type 3 design riprap/rock apron protection plan for Configuration 2 involved a transition grouted rock apron section that sloped away from the abutment at el 719.0 to the right down to el 716.0 for 18.3 m (60 ft) downstream of the end sill. A transition section of Class A riprap sloped from el 716.0 down to a horizontal bench at el 698.0 followed by a 1V on 1H slope down to el 691.0 (top of soft rock). The riprap protection along the abutment was the same as the riprap protection immediately downstream of the Configuration 1 grouted rock apron (Figure 6, Plates 34 and 35). Each of the steady-state conditions shown on pages A10 and A11 was run for 24 hours (prototype) for a factor of safety. The riprap remained stable throughout the range of flows investigated in the model. Flow conditions for each experiment are shown in Photos 16-35. Results of riprap stability experiments are presented in Table 8. Bottom velocities were measured to document flow conditions over the riprap and are shown in Plates 36-50.

The experiment schedule satisfies the requirements of EM 1110-2-1605[1] for investigation of half-open and fully open gates at normal pool with minimum tailwater.

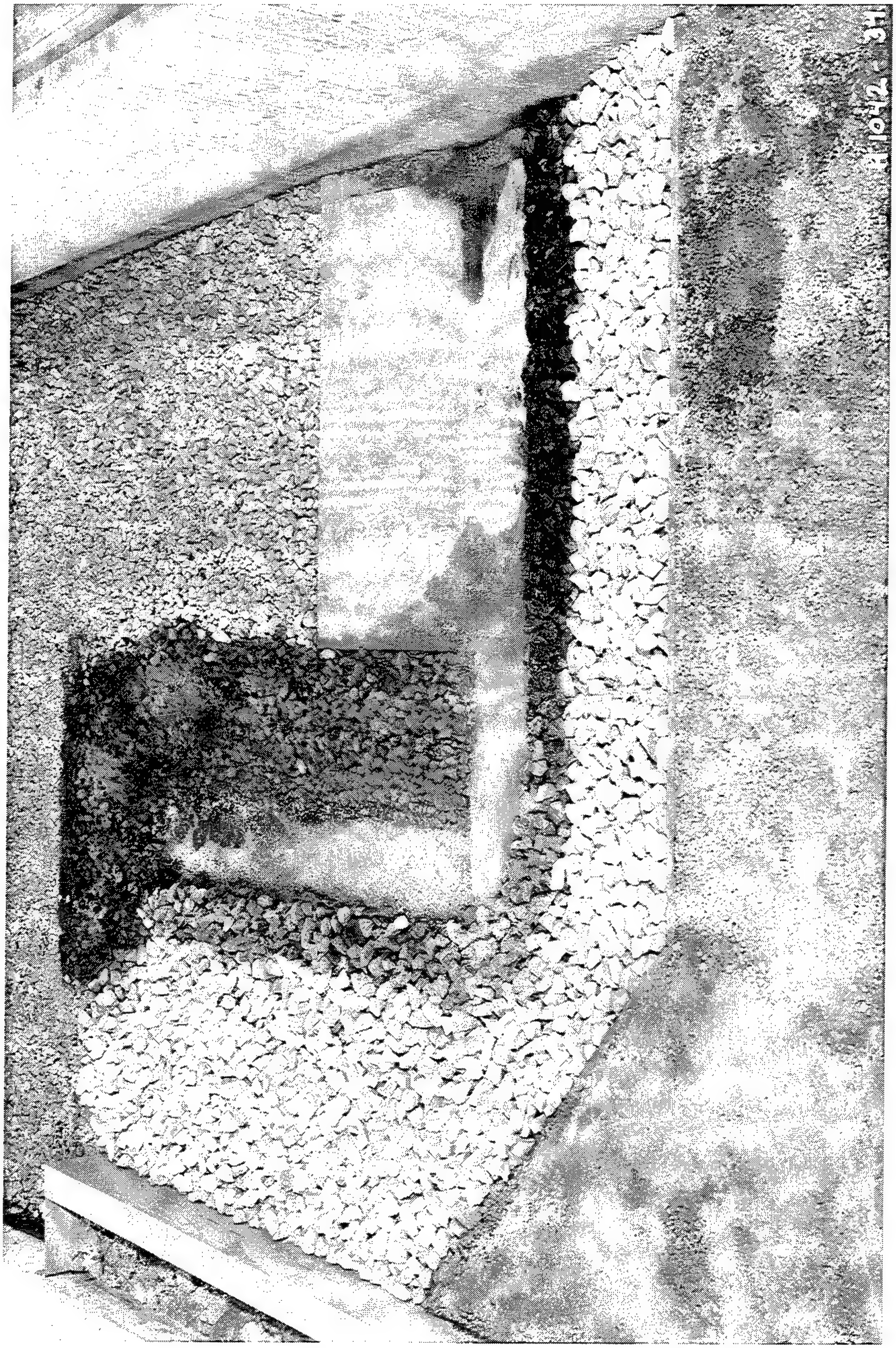
Upstream Stub Wall

A 17.7-m- (58-ft-) wide and 17.1-m- (56-ft-) long stub wall was simulated in the model upstream of the dam along the lock wall as shown in Plate 51 and Figure 7. The Pittsburgh District engineers requested experiments to analyze the scour caused by the stub wall in the prototype. Each of the steady-state conditions in the tabulation on page A12 was run to simulate discrete discharges for a hydrograph provided by the Pittsburgh District. Soundings were measured in the model, and the resulting scour contours were plotted in

[1] Headquarters, U.S. Army Corps of Engineers. (1987(12 May)). "Hydraulic design of navigation dams," EM 1110-2-1605, U.S. Government Printing Office, Washington, DC.

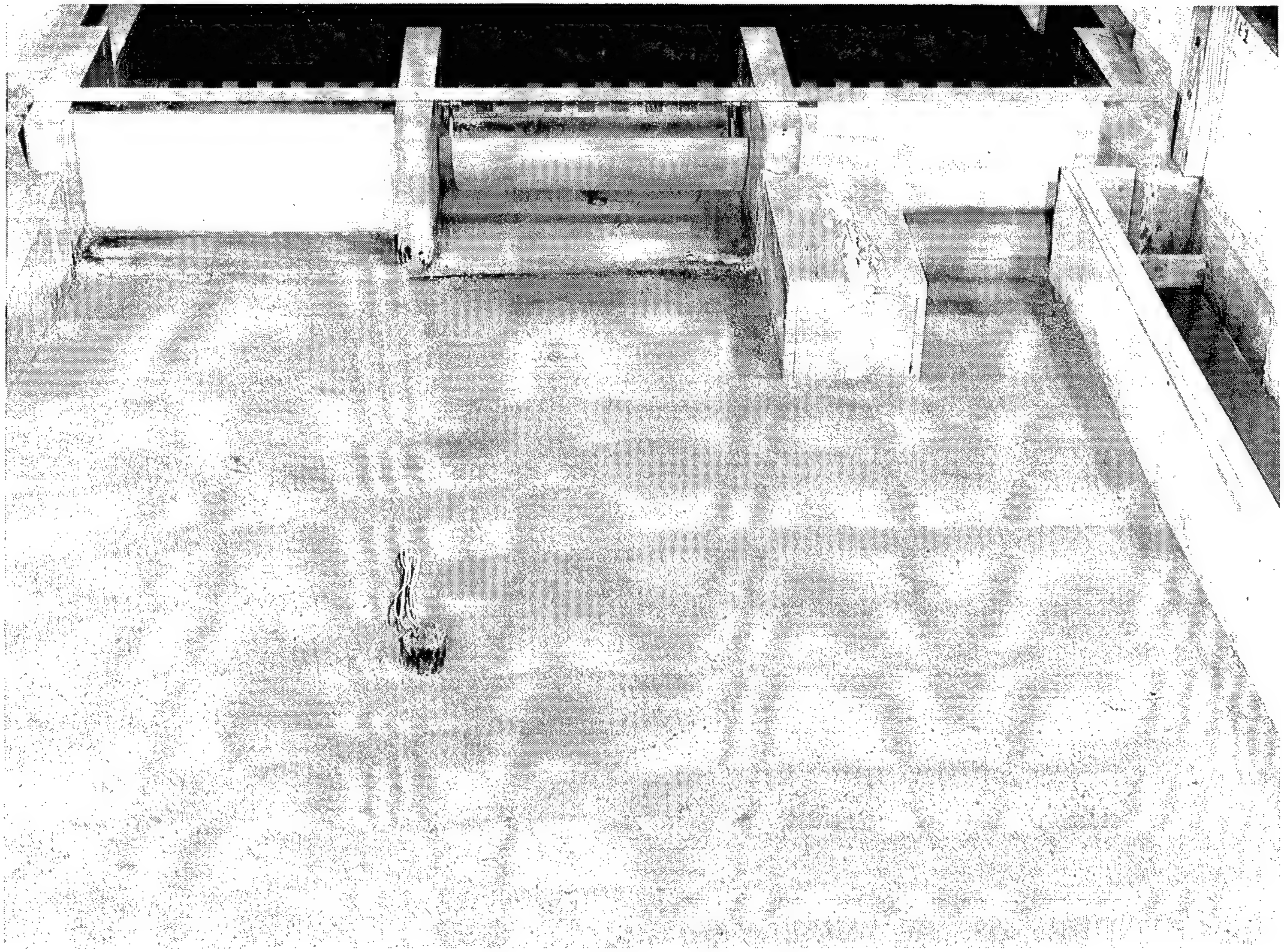
a. Looking upstream

Figure 6. Type 3 riprap/rock apron protection (Continued)



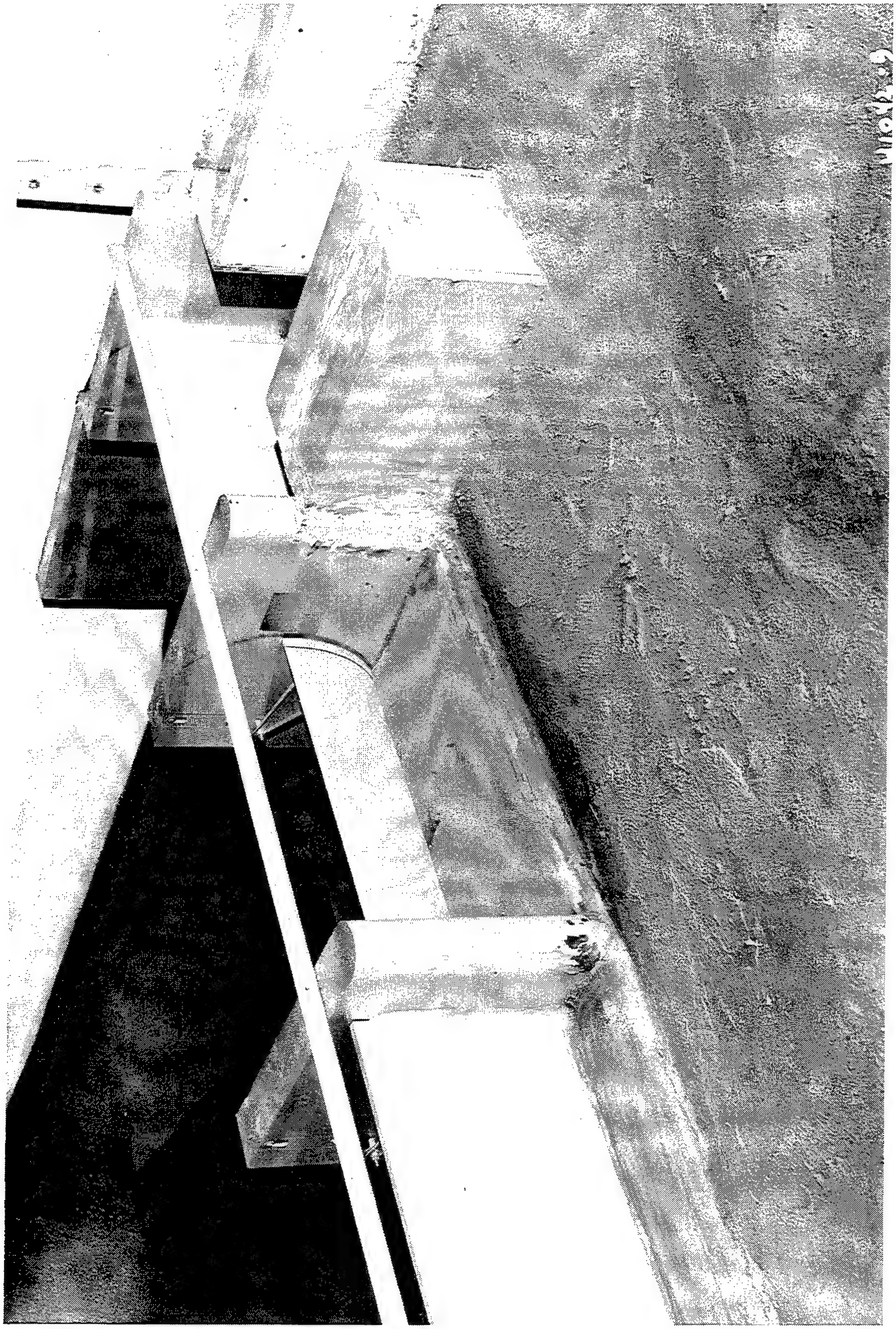
b. Looking downstream

Figure 6. (Concluded)



a. Looking downstream

Figure 7. Type 1 (original) stub wall, dry bed (Continued)



b. Side view

Figure 7. (Concluded)

Plate 52 and shown in Figure 8. Scour depths to el 704 were recorded in the immediate vicinity of the stub wall and to el 718 near the dam face.

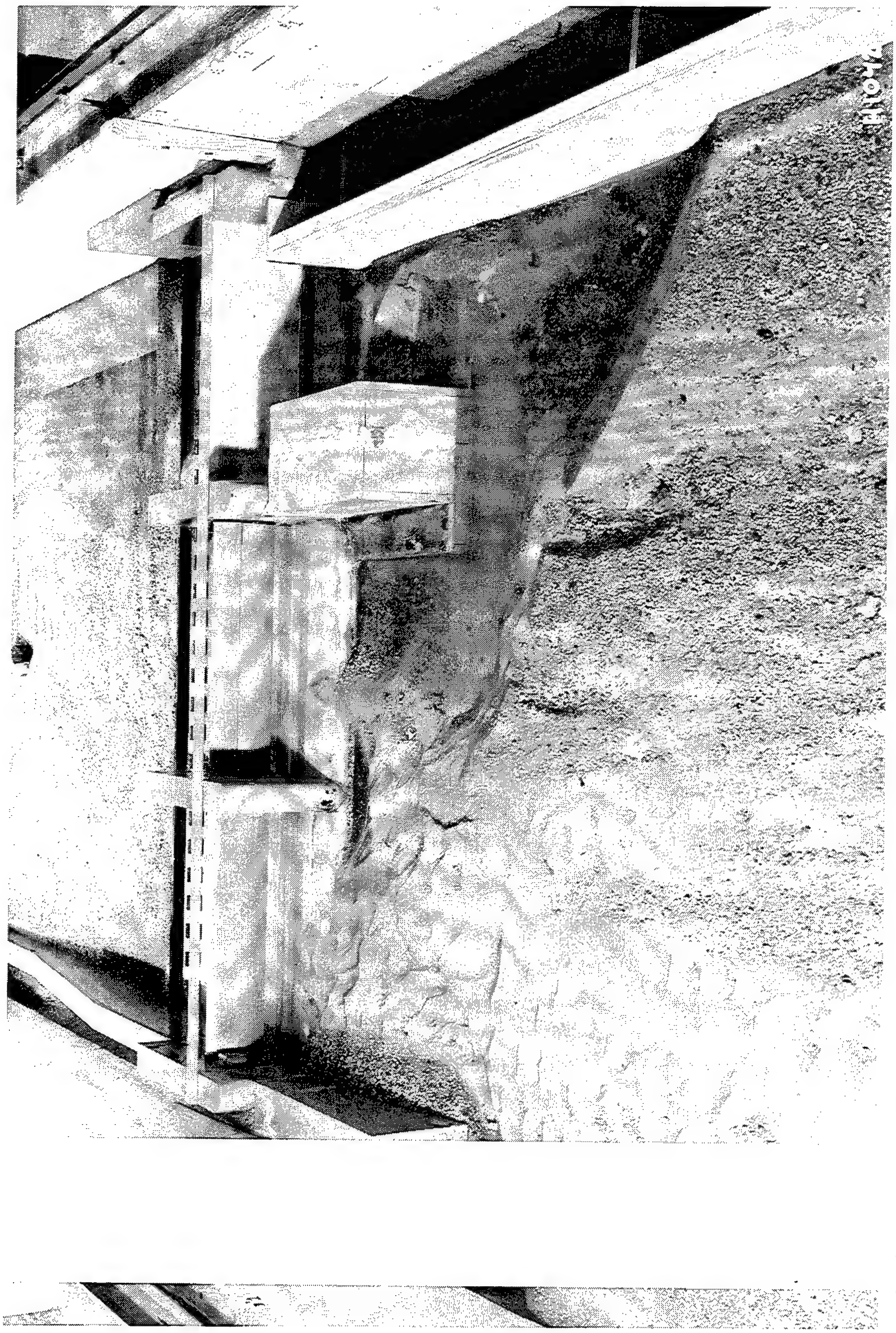
The stub wall was extended 171.6 m (563 ft) upstream (Plate 53) to simulate future proposed conditions with the new lock that might alleviate the potential for severe scour near the upstream face of the dam. Each of the steady-state conditions in the tabulation on page A12 for proposed conditions was run to simulate discrete discharges from a hydrograph provided by the Pittsburgh District. Soundings were measured in the model, and resulting scour contours were plotted in Plate 54. Extending the stub wall 171.6 (563 ft) decreased the potential for severe scour immediately upstream of the dam. Scour depths to el 720 were recorded near the upstream face of the dam.

Ice Experiments

Ice passage was investigated using two sizes of simulated ice to observe ice impact on the riprap protection downstream of the extended rock apron and to determine if ice would pass through smaller gate openings. Ice 0.2 m (0.75 ft) thick and 0.7-m (2.25-ft) thick was allowed to pass through one gate open 3 m (10 ft) with minimum tailwater, one gate fully open with minimum tailwater, and all three gates open 1.2 (4 ft) with minimum tailwater.

The 0.2-m- (0.75-ft-) thick ice passed rapidly through the gate during single gate operation (one gate open 3 m (10 ft) and one gate fully open) with no direct impact on the riprap protection downstream of the rock apron. The ice plunged in a rooster tail over the end sill, directly impacting the grouted rock apron and skimming along the top of the grouted rock apron along the water surface. During operation of the three gates (three gates open 1.2 m (4 ft)) the 0.2-m- (0.75-ft-) thick ice collected upstream of the gates clinging to the upstream gate skin, then slowly rolling along the skin down under the gates. Some ice became wedged upstream along the ends of the gates. Ice passage was much slower, with some pieces of ice becoming hung up on the baffles, then plunging in the rooster tail over the end sill, directly impacting the grouted rock apron and skimming along the top of the grouted rock apron. Again there was no direct impact of the ice on the riprap protection immediately downstream of the grouted rock apron.

The 0.7-m- (2.25-ft-) thick ice acted similar to the smaller, 0.2-m- (0.75-ft-) thick blocks of ice under all conditions evaluated. The results of these experiments are listed in Tables 9 and 10.



a. Looking downstream

Figure 8. Type 1 (original) stub wall scour, 69 hours (Continued)

b. Side view

Figure 8. (Concluded)

4 Conclusions

Results of experiments to determine the discharge characteristics of the Monongahela Dam 4 spillway indicated the four possible flow conditions that can be satisfied by the following equations:

a. *Free uncontrolled flow:*

$$Q = CLH^{3/2} \tag{1}$$

where C varies from 2.70 to 2.83.

b. *Submerged uncontrolled flow*:

$$Q = C_s Lh\sqrt{2g\Delta H} \tag{2}$$

where C_s varies from 0.85 to 1.01.

c. *Free controlled flow:*

$$Q = C_g LG_o\sqrt{2gH_g} \tag{3}$$

where C_g varies from 0.660 to 0.715.

d. *Submerged controlled flow*:

$$Q = C_{g_s} Lh\sqrt{2g\Delta H} \tag{4}$$

where C_{g_s} varies from 0.27 to 1.66.

It was beyond the scope of the model study to determine generalized functions for the coefficients. Analytical evaluations of the experimental data were conducted to assure that reasonable discharge coefficients were determined. Free and submerged discharge coefficients calculated from the experimental results from this model study were superimposed on HDC charts of established Corps discharge coefficients. While the experimental discharge coefficients did not match the HDC coefficients, it was determined that approach depth in the model was considerably different from the approach depth used for determination of the HDC coefficients.

Riprap stability experiments indicated that the type 3 riprap/rock apron protection plan (Plates 19 and 20, 34 and 35, and Figure 6) remained stable in the model through the full range of operation of gate bays 2-4 (Configuration 1) and gate bays 3-5 (Configuration 2), respectively. The type 3 riprap/rock apron protection plan involved extending the stilling basin apron 18.3 m (60 ft) followed by graded riprap (Class A) downstream and a zone of larger diameter uniformly sized stones (Class B) at the toe of the slope. The riprap remained stable throughout the range of flows investigated in the model for Configurations 1 (gate bays 2-4) and 2 (gate bays 3-5). Results of riprap stability experiments are presented in Tables 7 and 8. Bottom velocities were measured to document flow conditions over the riprap and are shown in Plates 22-32 and 36-50. Because this riprap protection plan remained stable for both configurations, it is recommended for prototype construction.

Riprap by itself (without a stilling basin extension) was found to be unstable under some expected operating conditions. While the Type 2 riprap protection plan showed some promise, failures occurred under single gate debris passing experiments under Configuration 1, and under ordinary operating conditions with one gate out of service under Configuration 2. Replacing broken baffles and/or altering the end sill will not compensate for these deficiencies.

Experiments to analyze the scour caused by a 17.7-m- (58-ft-) wide and 17.1-m- (56-ft-) long stub wall upstream of the dam along the lock wall indicated severe scour potential near the stub wall and the dam face. Extending the stub wall upstream 171.6 m (563 ft) in the model decreased the scour potential markedly.

As summarized in Tables 9 and 10, and the section "Ice Experiments," in Chapter 3, ice passage was documented using two sizes of simulated ice to observe ice impact on the riprap protection downstream of the extended rock apron and to determine if ice would pass through smaller gate openings. Ice 0.2 m (0.75 ft) thick and 0.7 m (2.25 ft) thick was allowed to pass through one gate open 3 m (10 ft) at normal pool (el 743.5) with minimum tailwater (el 723.7), one gate fully open at normal pool (el 743.5) with minimum tailwater (el 723.7), and all three gates open 1.2 m (4 ft) at normal pool (el 743.5) with minimum tailwater (el 723.7). The ice did not impact the riprap protection

plunged downward and skimmed the surface. The ice impacted the basin and the rock apron before flowing downstream along the surface above the riprap protection.

Table 1
Basic Calibration Data, Free Uncontrolled Flow, Crest El 724.0

Q cu m/sec (cfs)	Tailwater El	Headwater El	*H* m (ft)	*C*
350 (12,500)	733.0	738.5	4.4 (14.5)	2.70
420 (15,000)	733.0	740.3	5.0 (16.3)	2.71
504 (18,000)	735.0	741.9	5.5 (17.9)	2.83
560 (20,000)	735.0	743.3	5.9 (19.3)	2.81

Note: Symbols are defined following Equations 1-4 in text.

Table 2
Basic Calibration Data, Submerged Uncontrolled Flow, Crest El 724.0

Q cu m/sec (cfs)	Tailwater El	Headwater El	*H*, m (ft)	*h*, m (ft)	C_s	*h/H*
350 (12,500)	736.0	739.1	4.6 (15.1)	3.7 (12.0)	0.88	0.795
	738.0	740.4	5.0 (16.4)	4.3 (14.0)	0.86	0.854
	739.5	741.5	5.3 (17.5)	4.7 (15.5)	0.85	0.886
	740.0	741.8	5.4 (17.8)	4.9 (16.0)	0.86	0.899
	741.0	742.6	5.7 (18.6)	5.2 (17.0)	0.86	0.914
	742.0	743.4	5.9 (19.4)	5.5 (18.0)	0.87	0.928
	742.5	743.8	6.0 (19.8)	5.6 (18.5)	0.88	0.934
420 (15,000)	738.0	741.1	5.2 (17.1)	4.3 (14.0)	0.90	0.819
	739.0	741.6	5.4 (17.6)	4.6 (15.0)	0.92	0.852
	739.5	742.1	5.5 (18.1)	4.7 (15.5)	0.89	0.856
	741.0	743.2	5.9 (19.2)	5.2 (17.0)	0.88	0.885
	742.0	744.0	6.1 (20.0)	5.5 (18.0)	0.87	0.900
560 (20,000)	740.0	743.4	5.9 (19.4)	4.9 (16.0)	1.01	0.825
	741.0	744.3	6.2 (20.3)	5.2 (17.0)	0.96	0.837

Note: Symbols are defined following Equations 1-4 in text.

Table 3
Basic Calibration Data, Free Controlled Flow, Crest El 724.0

G_o, m (ft)	Q, cu m/sec (cfs)	Tailwater El	Headwater El	H_g, m (ft)	C_g
1.2 (4)	140 (5,000)	726.0	734.0	2.4 (8.0)	0.656
	168 (6,000)	726.0	736.6	3.2 (10.6)	0.683
	196 (7,000)	726.0	739.7	4.2 (13.7)	0.701
	210 (7,500)	726.0	741.4	4.7 (15.4)	0.709
	216 (7,700)	726.0	742.2	4.9 (16.2)	0.710
	221 (7,900)	726.0	742.8	5.1 (16.8)	0.715
	224 (8,000)	726.0	743.5	5.3 (17.5)	0.709
1.8 (6)	224 (8,000)	729.0	736.6	2.9 (9.6)	0.638
	280 (10,000)	729.0	740.5	4.1 (13.5)	0.673
	291 (10,400)	730.0	741.6	4.5 (14.6)	0.673
2.4 (8)	280 (10,000)	732.0	736.2	2.5 (8.2)	0.648
	308 (11,000)	732.0	738.3	3.1 (10.3)	0.636
	350 (12,500)	734.0	742.6	4.5 (14.6)	0.607
	375 (13,400)	734.0	743.5	4.7 (15.5)	0.631
3.0 (10)	434 (15,500)	734.0	743.7	4.5 (14.7)	0.600

Note: Symbols are defined following Equations 1-4 in text.

Table 4
Basic Calibration Data, Submerged Controlled Flow, Crest El 724.0

G_o, m (ft)	Q, cfs	Tailwater El	Headwater El	H_g, m (ft)	h, m (ft)	C_{gs}	h/G_o
1.2 (4)	140 (5,000)	731.0	734.2	2.5 (8.2)	1.5 (5.0)	0.83	1.3
		732.0	735.4	2.9 (9.4)	1.8 (6.0)	0.67	1.5
		733.0	737.4	3.5 (11.4)	2.1 (7.0)	0.51	1.8
		734.0	738.7	3.9 (12.7)	2.4 (8.0)	0.43	2.0
		735.0	739.9	4.2 (13.9)	2.7 (9.0)	0.37	2.3
		736.9	742.1	4.9 (16.1)	3.3 (10.9)	0.30	2.7
		738.0	743.3	5.3 (17.3)	3.6 (12.0)	0.27	3.0
	168 (6,000)	732.0	736.9	3.3 (10.9)	1.8 (6.0)	0.67	1.5
		733.0	738.2	3.7 (12.2)	2.1 (7.0)	0.56	1.8
		734.0	740.9	4.5 (14.9)	2.4 (8.0)	0.42	2.0
		735.0	742.3	5.0 (16.3)	2.7 (9.0)	0.37	2.3
		736.0	743.5	5.3 (17.5)	3.0 (10.0)	0.33	2.5
	196 (7,000)	732.0	739.9	4.2 (13.9)	1.8 (6.0)	0.62	1.5
		733.0	740.3	4.4 (14.3)	2.1 (7.0)	0.55	1.8
		734.2	742.5	5.0 (16.5)	2.5 (8.2)	0.44	2.1
	210 (7,500)	732.0	741.5	4.7 (15.5)	1.8 (6.0)	0.60	1.5
		733.0	741.9	4.8 (15.9)	2.1 (7.0)	0.53	1.8
		734.0	743.5	5.3 (17.5)	2.4 (8.0)	0.45	2.0
1.8 (6)	140 (5,000)	732.0	733.4	2.0 (6.4)	1.5 (5.0)	1.25	0.8
		734.0	735.7	2.7 (8.7)	2.1 (7.0)	0.81	1.2
		736.0	738.0	3.4 (11.0)	2.7 (9.0)	0.58	1.5
		738.0	740.3	4.1 (13.3)	3.4 (11.0)	0.44	1.8
		740.0	742.5	4.7 (15.5)	4.0 (13.0)	0.36	2.2
		741.5	744.1	5.2 (17.1)	4.4 (14.5)	0.32	2.4
	168 (6,000)	739.0	742.5	4.7 (15.5)	3.6 (12.0)	0.40	2.0
		740.0	743.5	5.0 (16.5)	4.0 (13.0)	0.37	2.2
		740.5	744.1	5.2 (17.1)	4.1 (13.5)	0.35	2.3
	224 (8,000)	734.0	737.5	3.2 (10.5)	2.1 (7.0)	0.91	1.2
		735.0	739.5	3.8 (12.5)	2.4 (8.0)	0.70	1.3
		736.0	741.2	4.3 (14.2)	2.7 (9.0)	0.58	1.5
		737.0	742.8	4.8 (15.8)	3.0 (10.0)	0.49	1.7
		738.0	743.9	5.2 (16.9)	3.4 (11.0)	0.44	1.8
	280 (10,000)	734.0	740.8	4.2 (13.8)	2.1 (7.0)	0.81	1.2
		735.0	741.4	4.4 (14.4)	2.4 (8.0)	0.73	1.3
		736.1	743.1	4.9 (16.1)	2.8 (9.1)	0.62	1.5
	291 (10,400)	735.0	742.1	4.6 (15.1)	2.4 (8.0)	0.72	1.3
		736.0	743.5	5.0 (16.5)	1.5 (9.0)	0.63	1.5
2.4 (8)	168 (6,000)	733.0	734.4	2.0 (6.4)	1.5 (5.0)	1.50	0.6
		734.1	735.2	2.2 (7.2)	1.9 (6.1)	1.39	0.8
		735.0	736.0	2.4 (8.0)	2.1 (7.0)	1.27	0.9
		736.1	737.3	2.8 (9.3)	2.5 (8.1)	1.00	1.0
		737.0	738.2	3.1 (10.2)	2.7 (9.0)	0.90	1.1
		737.8	739.2	3.4 (11.2)	3.0 (9.8)	0.77	1.2
		738.8	740.3	3.7 (12.3)	3.3 (10.8)	0.67	1.4

(Continued)

Note: Symbols are defined following Equations 1-4 in text.

Table 4 (Concluded)							
G_o, m (ft)	Q, cfs	Tailwater El	Headwater El	H_g, m (ft)	h, m (ft)	C_{gs}	h/G_o
2.4 (8) (Cont.)	168 (6,000) (Cont.)	740.8	742.5	4.4 (14.5)	3.9 (12.8)	0.53	1.6
		742.9	744.9	5.2 (16.9)	4.5 (14.9)	0.42	1.9
	224 (8,000)	733.0	735.4	2.3 (7.4)	1.5 (5.0)	1.53	0.6
		734.0	735.9	2.4 (7.9)	1.8 (6.0)	1.44	0.8
		735.0	737.0	2.7 (9.0)	2.1 (7.0)	1.20	0.9
		736.3	738.7	3.3 (10.7)	2.5 (8.3)	0.92	1.0
		737.0	739.7	3.6 (11.7)	2.7 (9.0)	0.80	1.1
		738.0	740.7	3.9 (12.7)	3.0 (10.0)	0.72	1.3
		739.9	743.1	4.6 (15.1)	3.6 (11.9)	0.56	1.5
	280 (10,000)	735.0	737.5	2.9 (9.5)	2.1 (7.0)	1.34	0.9
		736.0	739.0	3.4 (11.0)	2.4 (8.0)	1.07	1.0
		737.0	741.0	4.0 (13.0)	2.7 (9.0)	0.82	1.1
		738.0	742.5	4.4 (14.5)	3.0 (10.0)	0.70	1.3
		739.0	743.8	4.8 (15.8)	3.4 (11.0)	0.62	1.4
	308 (11,000)	735.0	738.8	3.3 (10.8)	2.1 (7.0)	1.20	0.9
		736.0	740.1	3.7 (12.1)	2.4 (8.0)	1.01	1.0
		737.2	742.0	4.3 (14.0)	2.8 (9.2)	0.81	1.2
		738.0	743.6	4.8 (15.6)	3.0 (10.0)	0.69	1.3
	350 (12,500)	736.0	742.8	4.5 (14.8)	2.4 (8.0)	0.89	1.0
		737.0	743.6	4.8 (15.6)	2.7 (9.0)	0.80	1.1
3.0 (10)	350 (12,500)	736.0	739.3	3.1 (10.3)	2.1 (7.0)	1.46	0.7
		737.0	740.7	3.6 (11.7)	2.4 (8.0)	1.21	0.8
		738.2	742.5	4.1 (13.5)	2.8 (9.2)	0.97	0.9
		739.0	744.3	4.7 (15.3)	3.0 (10.0)	0.81	1.0
	280 (10,000)	740.0	743.0	4.3 (14.0)	3.4 (11.0)	0.78	1.1
		740.5	744.1	4.6 (15.1)	3.5 (11.5)	0.68	1.2
	420 (15,000)	737.0	742.9	4.2 (13.9)	2.4 (8.0)	1.15	0.8
		737.4	743.4	4.4 (14.4)	2.6 (8.4)	1.08	0.8
		738.0	744.0	4.6 (15.0)	2.7 (9.0)	1.01	0.9
3.6 (12)	224 (8,000)	741.1	742.1	3.7 (12.1)	3.4 (11.1)	1.07	0.9
		742.0	743.2	4.0 (13.2)	3.7 (12.0)	0.90	1.0
	280 (10,000)	740.0	741.6	3.5 (11.6)	3.0 (10.0)	1.17	0.8
		741.0	742.8	3.9 (12.8)	3.4 (11.0)	1.01	0.9
	350 (12,500)	738.0	740.4	3.2 (10.4)	2.4 (8.0)	1.50	0.7
		739.0	741.5	3.5 (11.5)	2.7 (9.0)	1.30	0.8
		740.0	743.1	4.0 (13.1)	3.0 (10.0)	1.05	0.8
		741.0	744.5	4.4 (14.5)	3.4 (11.0)	0.90	0.9
	420 (15,000)	738.0	740.8	3.3 (10.8)	2.4 (8.0)	1.66	0.7
		738.8	741.9	3.6 (11.9)	2.7 (8.8)	1.44	0.7
		739.8	743.3	4.1 (13.3)	3.0 (9.8)	1.21	0.8
	504 (18,000)	739.0	743.7	4.2 (13.7)	2.7 (9.0)	1.37	0.8
		740.0	745.5	4.7 (15.5)	3.0 (10.0)	1.14	0.8

Table 5
Basic Calibration Data, Normal Pool El 743.5, Crest El 724.0

G_o, m (ft)	Q, cu m/sec (cfs)	Tailwater El
1.2 (4)	140 (5,000)	737.3
	168 (6,000)	736.0
	196 (7,000)	734.7
	210 (7,500)	734.0
	224 (8,000)	732.0
1.8 (6)	140 (5,000)	740.9
	168 (6,000)	740.0
	224 (8,000)	737.7
	280 (10,000)	736.3
	291 (10,400)	736.0
	308 (11,000)	735.0
	314 (11,200)	734.0
2.4 (8)	168 (6,000)	741.7
	224 (8,000)	740.2
	280 (10,000)	738.6
	308 (11,000)	737.9
	350 (12,500)	736.9
	375 (13,400)	732.0
3.0 (10)	280 (10,000)	740.4
	350 (12,500)	739.5
	420 (15,000)	737.7
	431 (15,400)	736.0
3.6 (12)	224 (8,000)	742.3
	280 (10,000)	741.5
	350 (12,500)	740.4
	420 (15,000)	737.9
	504 (18,000)	738.8
Full	350 (12,500)	742.1
	420 (15,000)	741.5
	504 (18,000)	740.7
	560 (20,000)	740.1
	574 (20,500)	738.8

Note: Symbols are defined following Equations 1-4 in text.

Table 6
Riprap Stability Analysis, Type 2 Design Riprap 2.6 m (8.5 ft) Thick

Experiment	Q cu m/sec (cfs)	Gate Opening, m (ft)			Pool El	Tailwater El	Stable or Failed t = 12 hr
		2	3	4			
1	129 (4,600)	0	0.6 (2)	0	743.5	723.7	Stable
2	482 (17,200)	0.6 (2)	1.2 (4)	0.6 (2)	743.5	726.8	Stable
3	1,005 (35,900)	1.8 (6)	2.4 (8)	1.8 (6)	743.5	733.5	Stable
4	1,366 (48,800)	3.0 (10)	3.6 (12)	3.0 (10)	743.5	737.1	Stable
5	1,537 (54,900)	3.6 (12)	Full	3.6 (12)	743.5	739.0	Stable
6	2,066 (73,800)	Full	Full	Full	746.9	745.2	Stable
7	762 (27,200)	1.2 (4)	1.8 (6)	1.2 (4)	743.5	730.6	Stable
8	1,204 (43,000)	2.4 (8)	3.0 (10)	2.4 (8)	743.5	735.5	Stable
9	1,630 (58,200)	Full	Full	Full	743.5	740.3	Stable
10	314 (11,200)	0	1.8 (6)	0	743.5	723.7	Failed
11	378 (13,500)	0	2.4 (8)	0	743.5	727.0	Failed
12	574 (20,500)	0	Full	0	743.5	729.0	Failed
13	538 (19,200)	1.2 (4)	0	1.8 (6)	743.5	728.9	Stable
14	826 (29,500)	3.0 (10)	0	2.4 (8)	743.5	733.1	Stable
15	1,078 (38,500)	3.6 (12)	0	Full	743.5	736.3	Stable

Table 7
Riprap Stability Analysis, Type 3 Design Riprap/Rock Apron, Configuration 1

Experiment	Q cu m/sec (cfs)	Gate Opening, m (ft)			Pool El	Tailwater El
		2	3	4		
1	129 (4,600)	0	0.6 (2)	0	743.5	723.7
2	482 (17,200)	0.6 (2)	1.2 (4)	0.6 (2)	743.5	726.8
3	1,005 (35,900)	1.8 (6)	2.4 (8)	1.2 (6)	743.5	733.5
4	1,366 (48,800)	3.0 (10)	3.6 (12)	3.0 (10)	743.5	737.1
5	1,537 (54,900)	3.6 (12)	Full	3.6 (12)	743.5	739.0
6	2,066 (73,800)	Full	Full	Full	746.9	745.2
7	762 (27,200)	1.6 (4)	1.8 (6)	1.2 (4)	743.5	730.6
8	1,193 (42,600)	2.4 (8)	3.0 (10)	2.4 (8)	743.5	735.5
9	1,630 (58,200)	Full	Full	Full	743.5	740.3
10	314 (11,200)	0	1.8 (6)	0	743.5	723.7
11	378 (13,500)	0	2.4 (8)	0	743.5	723.7
11a	437 (15,600)	0	3.0 (10)	0	743.5	723.7
12	574 (20,500)	0	Full	0	743.5	729.0
12a	574 (20,500)	0	Full	0	743.5	723.7
13	538 (19,200)	1.2 (4)	0	1.8 (6)	743.5	728.9
14	815 (29,100)	3.0 (10)	0	2.4 (8)	743.5	733.1
15	1,078 (38,500)	3.6 (12)	0	Full	743.5	736.3

Note: Riprap remained stable for all experiments after 24 hours (prototype).

Table 8
Riprap Stability Analysis, Type 3 Design Riprap/Rock Apron, Configuration 2

Experiment	Q cu m/sec (cfs)	Gate Opening, m (ft)			Pool El	Tailwater El
		3	4	5		
1	129 (4,600)	0.6 (2)	0	0	743.5	723.7
2	482 (17,200)	1.2 (4)	0.6 (2)	0.6 (2)	743.5	726.8
3	1,005 (35,900)	2.4 (8)	1.8 (6)	1.8 (6)	743.5	733.5
4	1,366 (48,800)	3.6 (12)	3.0 (10)	3.0 (10)	743.5	737.1
5	1,537 (54,900)	Full	3.6 (12)	3.6 (12)	743.5	739.0
6	2,066 (73,800)	Full	Full	Full	746.9	745.2
7	762 (27,200)	1.8 (6)	1.2 (4)	1.2 (4)	743.5	730.6
8	1,193 (42,600)	3.0 (10)	2.4 (8)	2.4 (8)	743.5	735.5
9	1,630 (58,200)	Full	Full	Full	743.5	740.3
10	314 (11,200)	0	0	1.8 (6)	743.5	723.7
10x	314 (11,200)	0	1.8 (6)	0	743.5	723.7
11	378 (13,500)	0	0	2.4 (8)	743.5	723.7
11x	378 (13,500)	0	2.4 (8)	0	743.5	723.7
11a	437 (15,600)	0	0	3.0 (10)	743.5	723.7
11ax	437 (15,600)	0	3.0 (10)	0	743.5	723.7
12	574 (20,500)	0	0	Full	743.5	729.0
12a	574 (20,500)	0	0	Full	743.5	723.7
12ax	574 (20,500)	0	Full	0	743.5	723.7
13	538 (19,200)	1.8 (6)	0	1.2 (4)	743.5	728.9
14	815 (29,100)	3.0 (10)	0	2.4 (8)	743.5	733.1
15	1,078 (38,500)	Full	0	3.6 (12)	743.5	736.3

Note: Riprap remained stable for all experiments after 24 hours (prototype).

Table 9
Ice Passage, Type 3 Riprap/Rock Apron, Configuration 2, 1.7-m- (5.5-ft-) long, 1.7-m- (5.5-ft-) wide, 0.2-m- (0.75-ft-) Thick Ice

Q cu m/sec (cfs)	G_o	Pool El	Tailwater El	Visual Observations
437 (15,600)	One gate open 3.0 m (10 ft)	743.5	723.7	Ice passed rapidly through the gate. Ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.
574 (20,500)	One gate open full	743.5	723.7	Ice passed rapidly through the gate. Ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.
672 (24,000)	Three gates open 1.2 m (4 ft)	743.5	723.7	Ice collected upstream of gates, clinging to the upstream gate skin, then slowly rolled along the skin down under the gates. Some ice wedged upstream along the ends of the gates. Once ice passed slowly through the gates, some pieces of ice hung up on the baffles, ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.

Table 10
Ice Passage, Type 3 Riprap/Rock Apron, Configuration 2, 1.8-m- (6.0-ft-) Long, 1.8-m- (6.0-ft-) Wide, 0.7-m- (2.25-ft-) Thick Ice

Q cu m/sec (cfs)	G_o	Pool El	Tailwater El	Visual Observations
437 (15,600)	One gate open 3.0 m (10 ft)	743.5	723.7	Ice passed rapidly through the gate. Ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.
574 (20,500)	One gate open full	743.5	723.7	Ice passed rapidly through the gate. Ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.
672 (24,000)	Three gates open 1.2 m (4 ft)	743.5	723.7	Ice collected upstream of gates, clinging to the upstream gate skin, then slowly rolled along the skin down under the gates. Some ice wedged upstream along the ends of the gates. Once ice passed slowly through the gates, some pieces of ice hung up on the baffles, ice plunged in the rooster tail over the end sill, directly impacting the rock apron and skimming along the top of the rock apron. No direct impact on the riprap protection downstream.

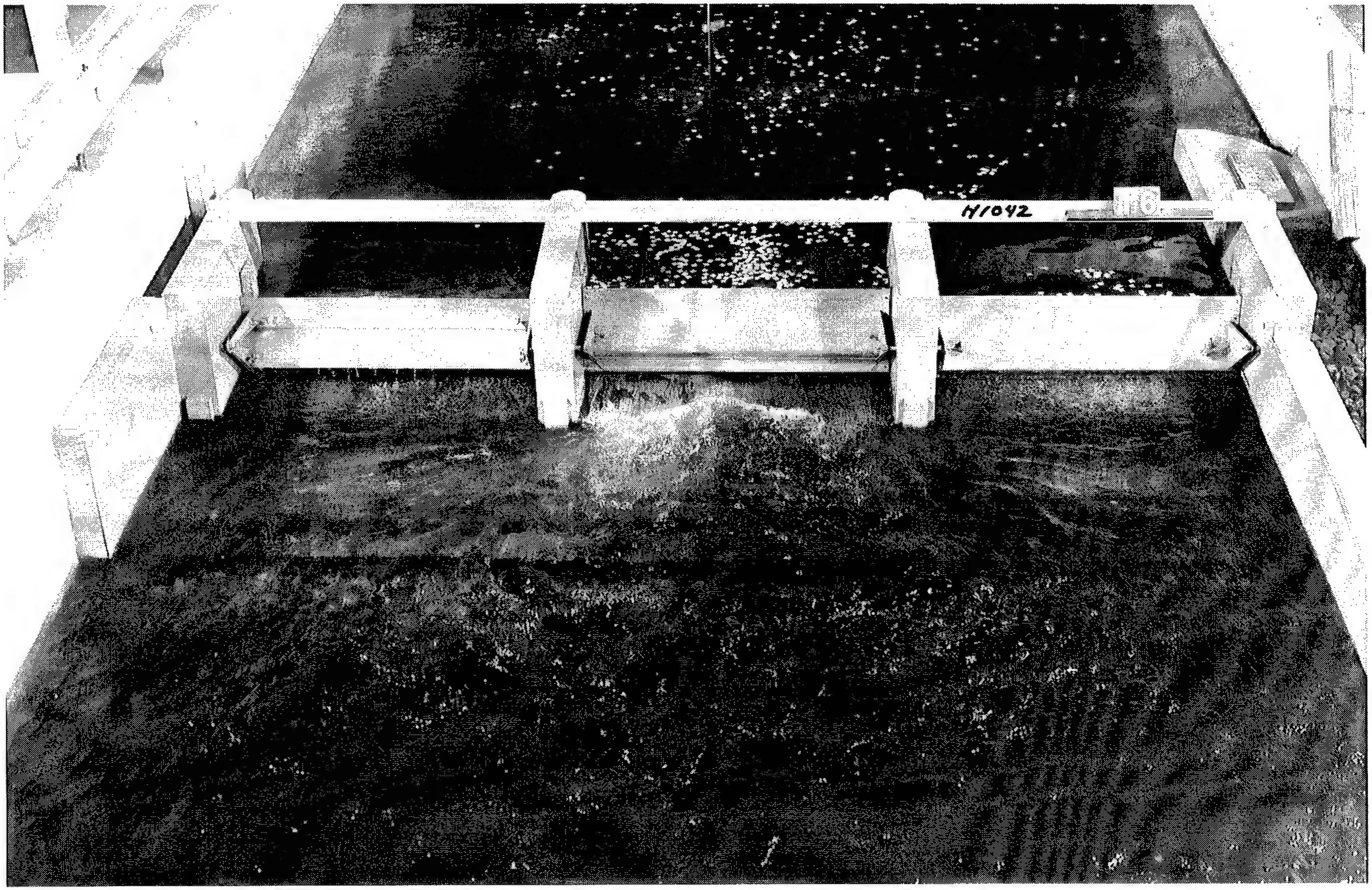


Photo 1. Type 2 riprap, configuration 1; Q = 129 cu m/sec (4,600 cfs); G_2 = 0, G_3 = 0.6 m (2 ft), G_4 = 0; pool el 743.5; tailwater el 730.6

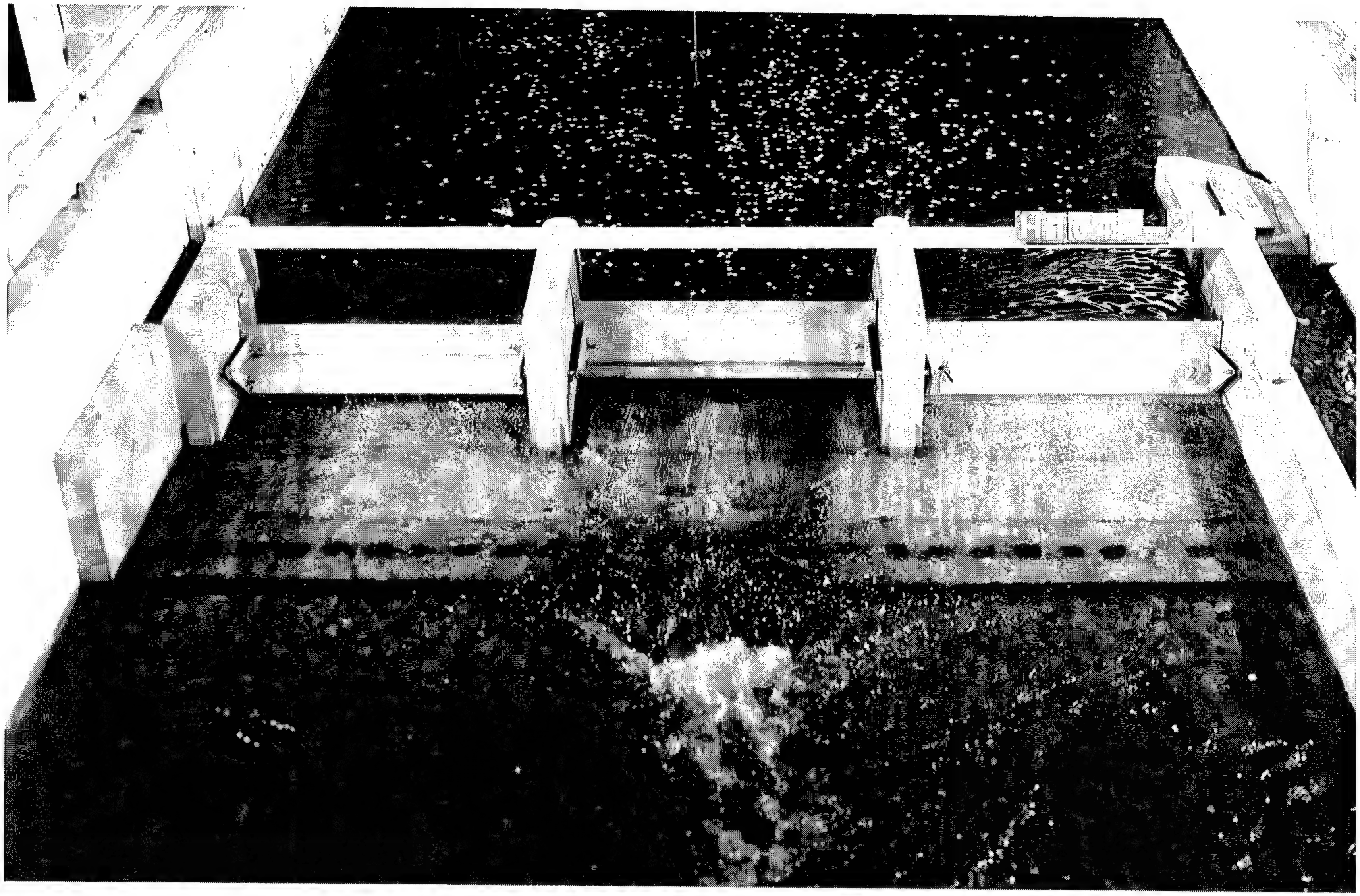


Photo 2. Type 2 riprap, Configuration 1; Q = 314 cu m/sec (11,200 cfs); G_2 = 0, G_3 = 1.8 m (6 ft), G_4 = 0; pool el 743.5; tailwater el 723.7

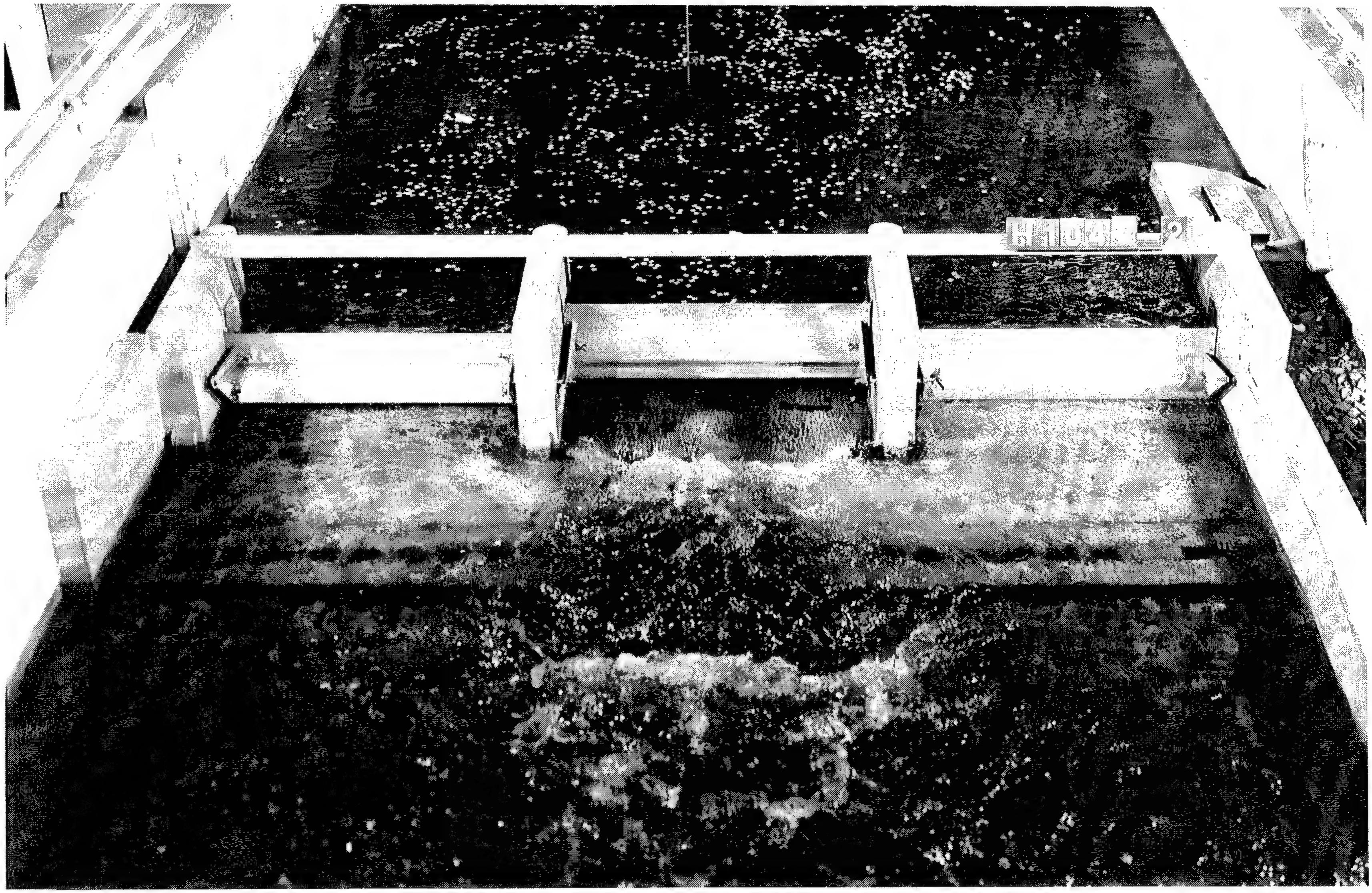


Photo 3. Type 2 riprap, Configuration 1; Q = 378 cu m/sec (13,500 cfs); G_2 = 0, G_3 = 2.4 m (8 ft), G_4 = 0; pool el 743.5; tailwater el 727.0

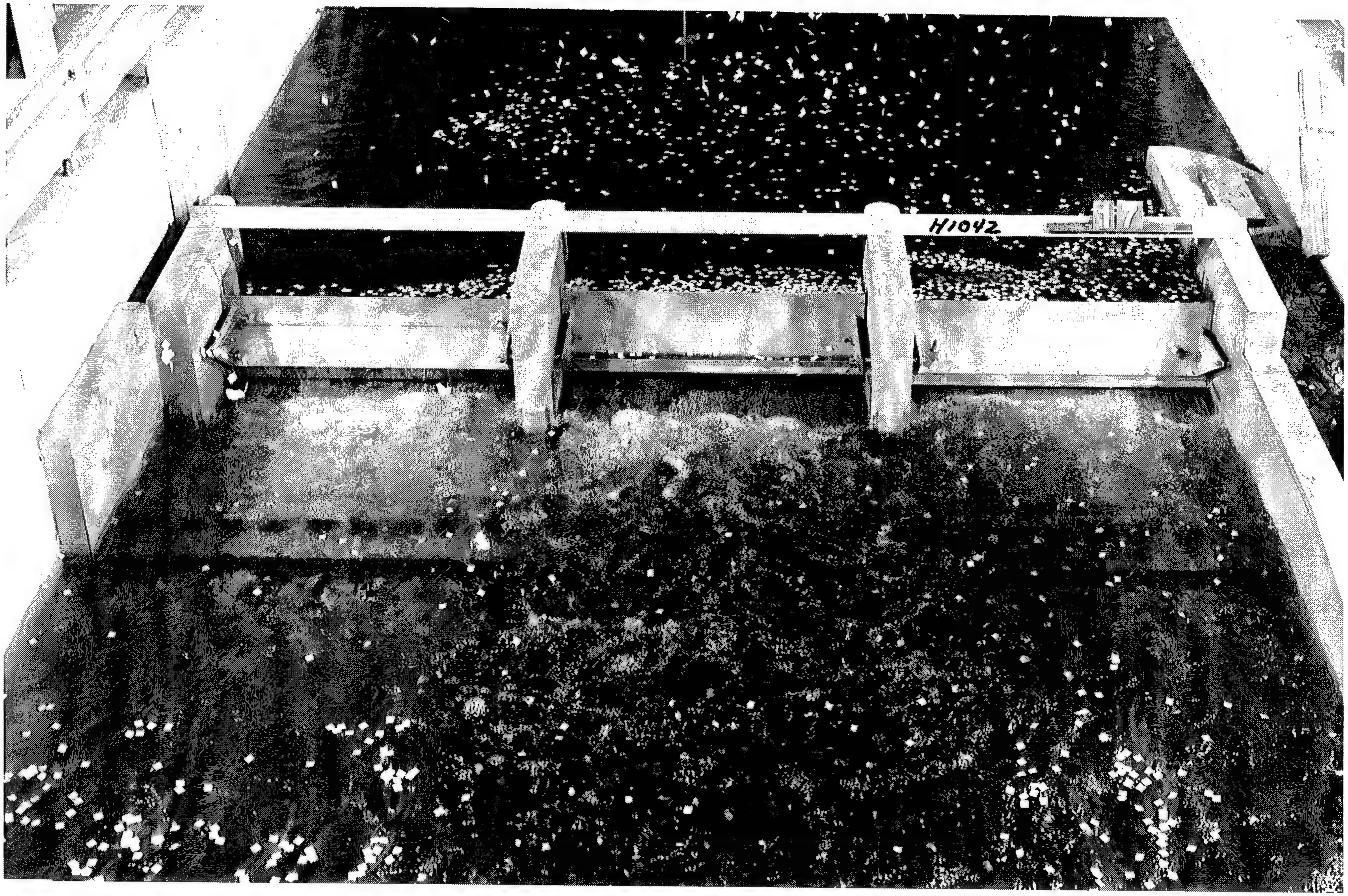


Photo 4. Type 2 riprap, Configuration 1; Q = 482 cu m/sec (17,200 cfs); G_2 = 0.6 m (2 ft), G_3 = 1.2 m (4 ft), G_4 = 0.6 m (2 ft); pool el 743.5; tailwater el 726.8

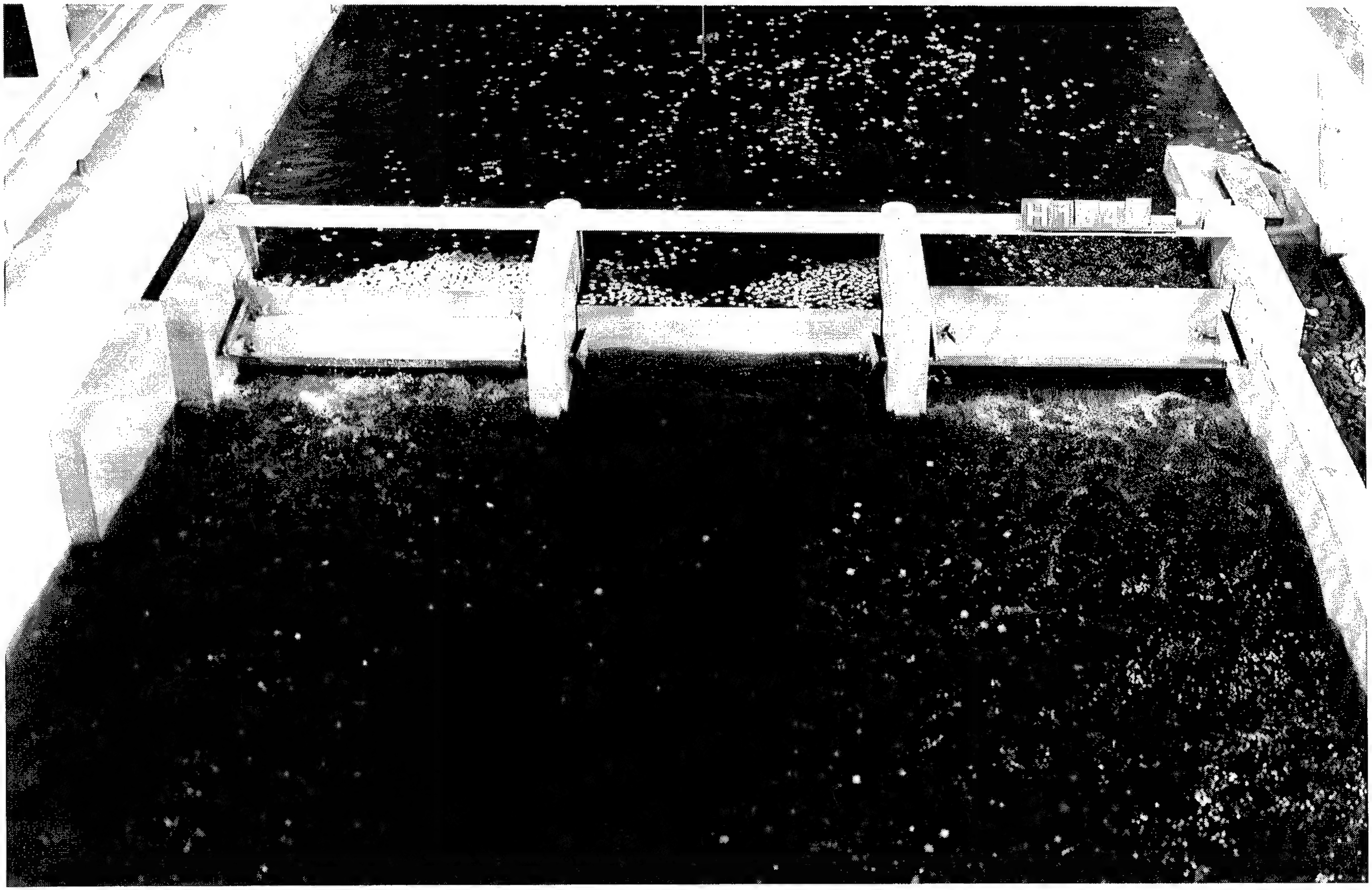


Photo 5. Type 2 riprap, Configuration 1; Q = 538 cu m/sec (19,200 cfs); G_2 = 1.2 m (4 ft), G_3 = 0, G_4 = 1.8 m (6 ft); pool el 743.5; tailwater el 728.9

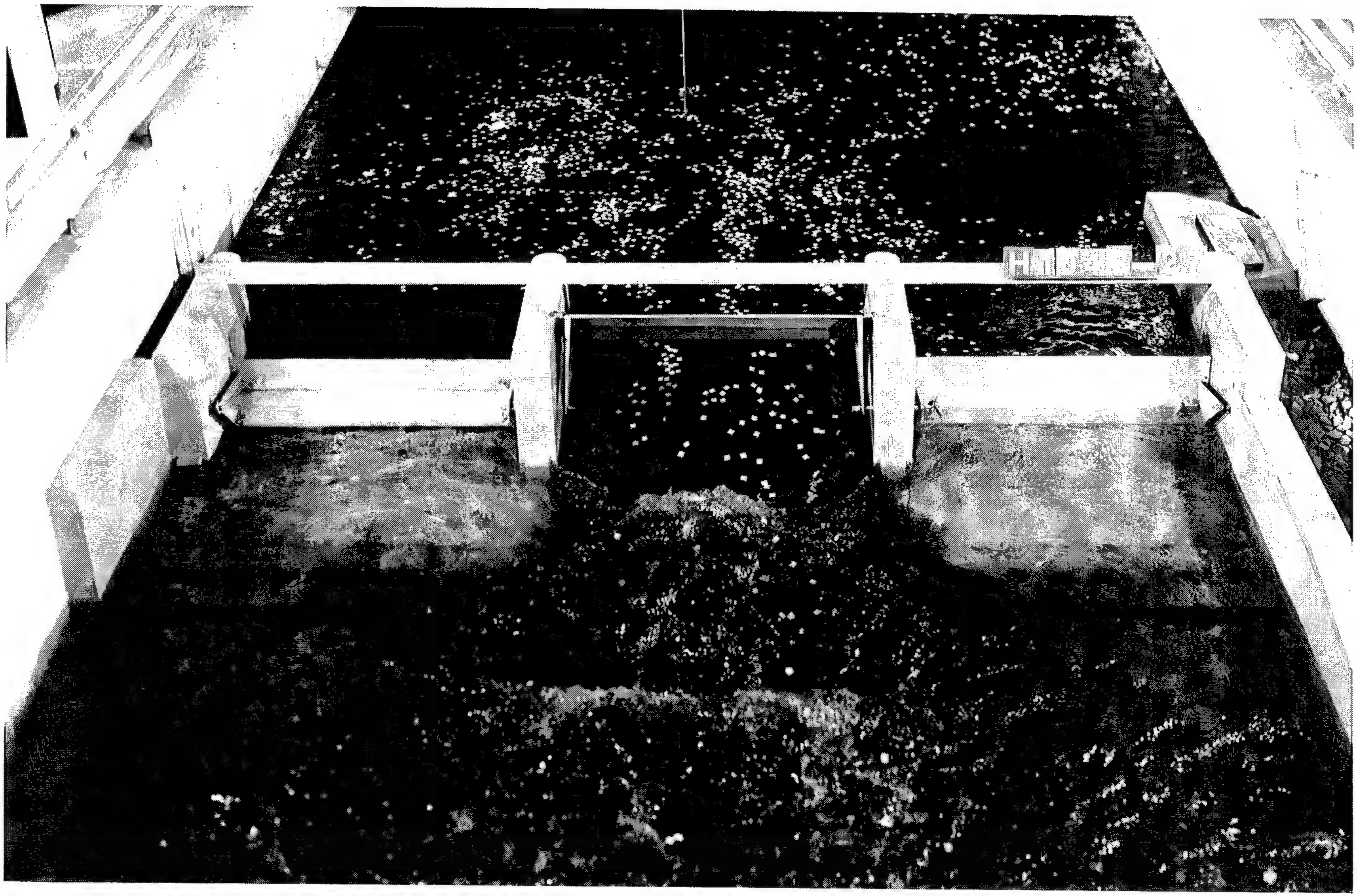


Photo 6. Type 2 riprap, Configuration 1; Q = 574 cu m/sec (20,500 cfs); G_2 = 0, G_3 = full, G_4 = 0; pool el 743.5; tailwater el 729.0

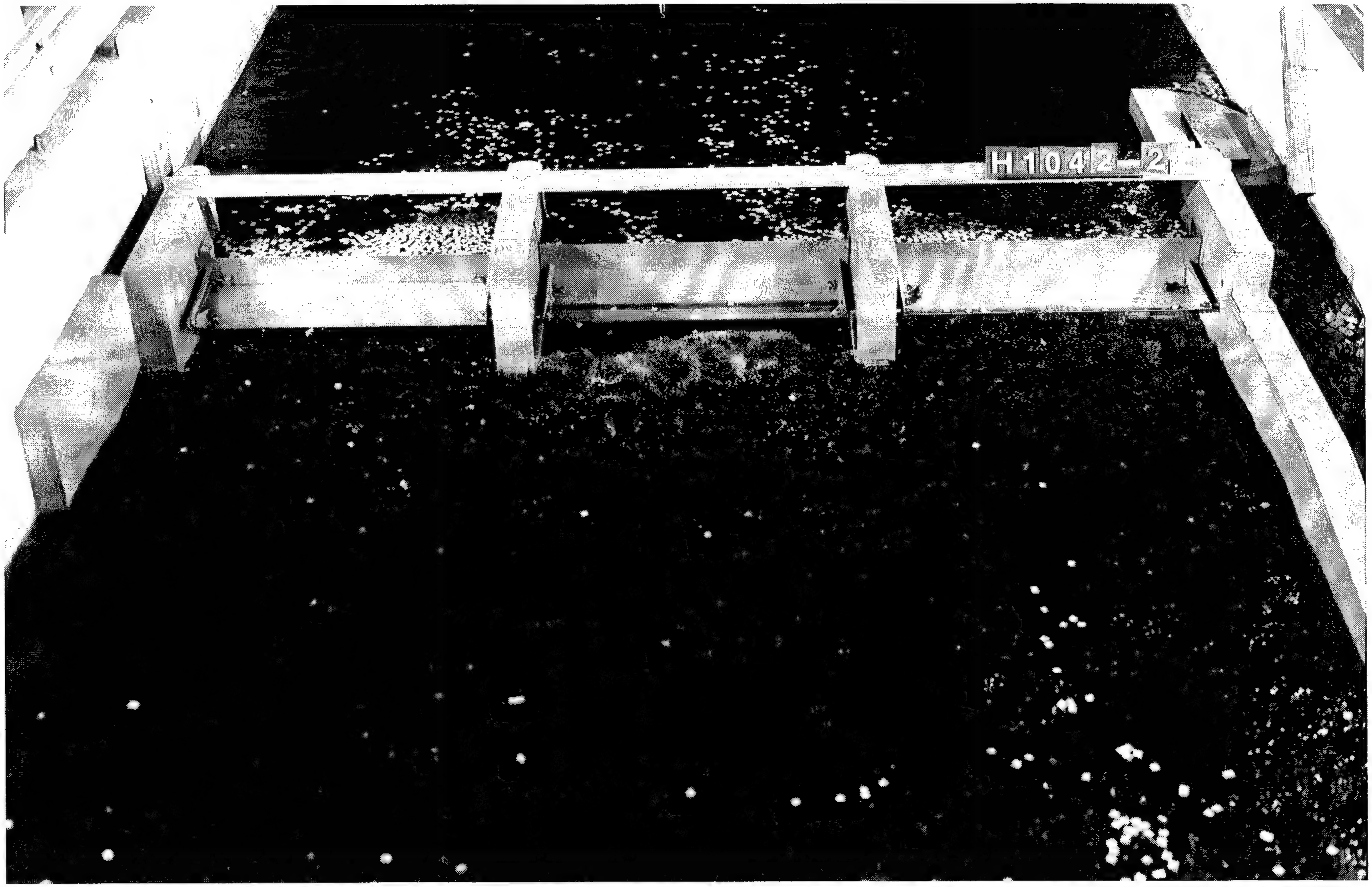


Photo 7. Type 2 riprap, Configuration 1; Q = 762 cu m/sec (27,200 cfs); G_2 = 1.2 m (4 ft), G_3 = 1.8 m (6 ft), G_4 = 1.2 m (4 ft); pool el 743.5; tailwater el 730.6

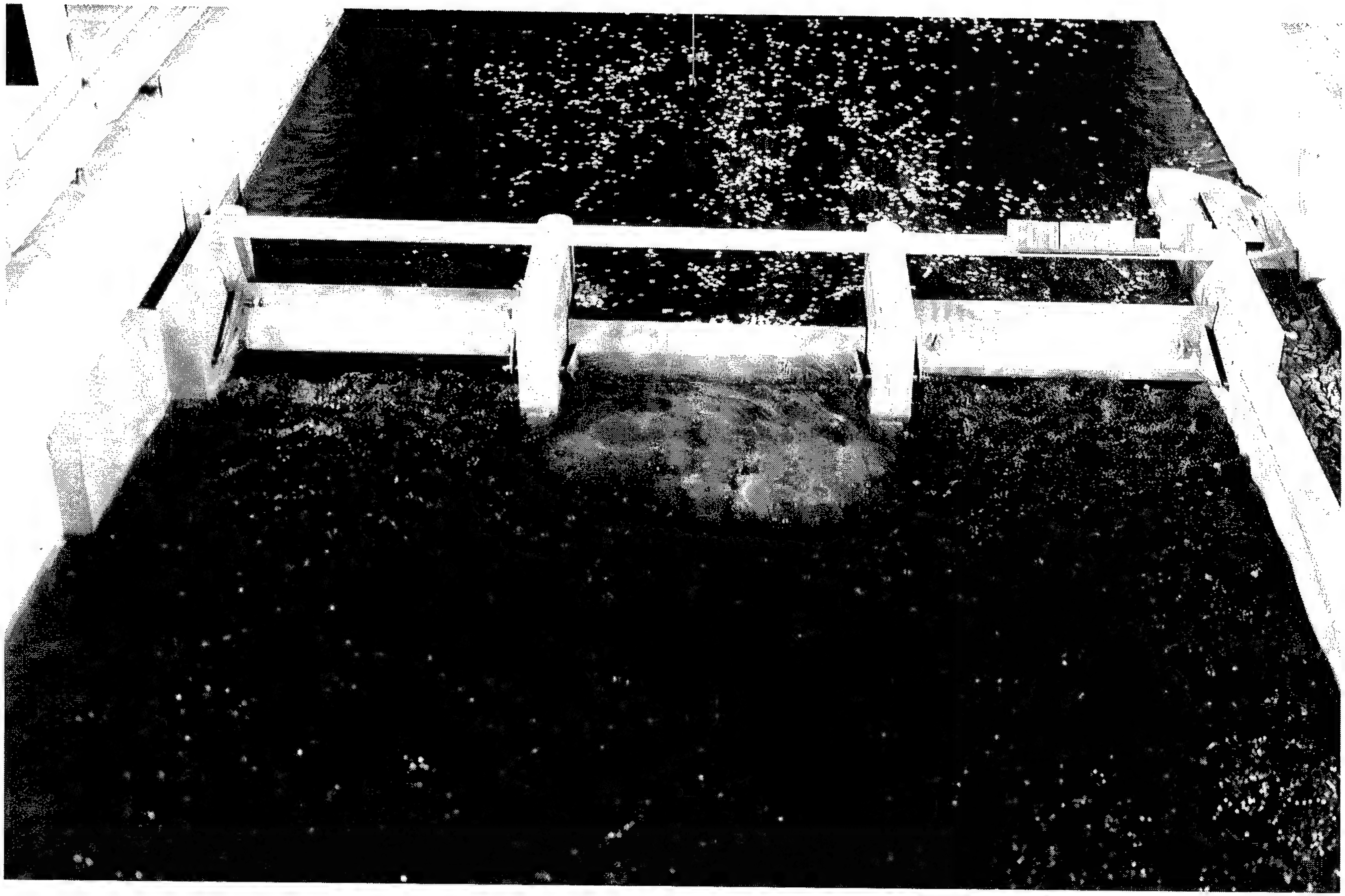


Photo 8. Type 2 riprap, Configuration 1; Q = 815 cu m/sec (29,100 cfs); G_2 = 3.0 m (10 ft), G_3 = 0, G_4 = 2.4 m (8 ft); pool el 743.5; tailwater el 733.1

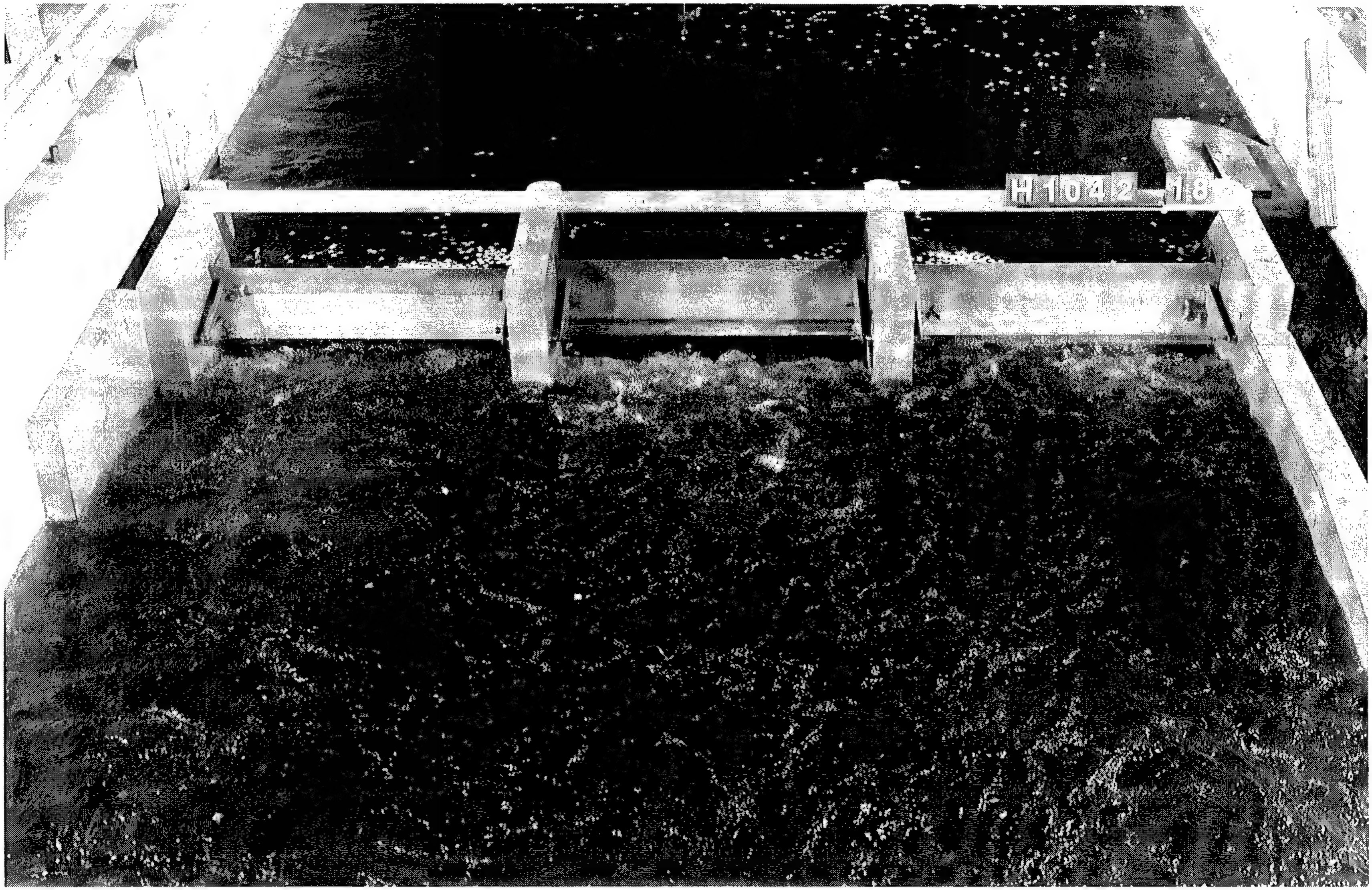


Photo 9. Type 2 riprap, Configuration 1; Q = 1,005 cu m/sec (35,900 cfs); G_2 = 1.8 m (6 ft), G_3 = 2.4 m (8 ft), G_4 = 1.8 m (6 ft); pool el 743.5; tailwater el 733.5

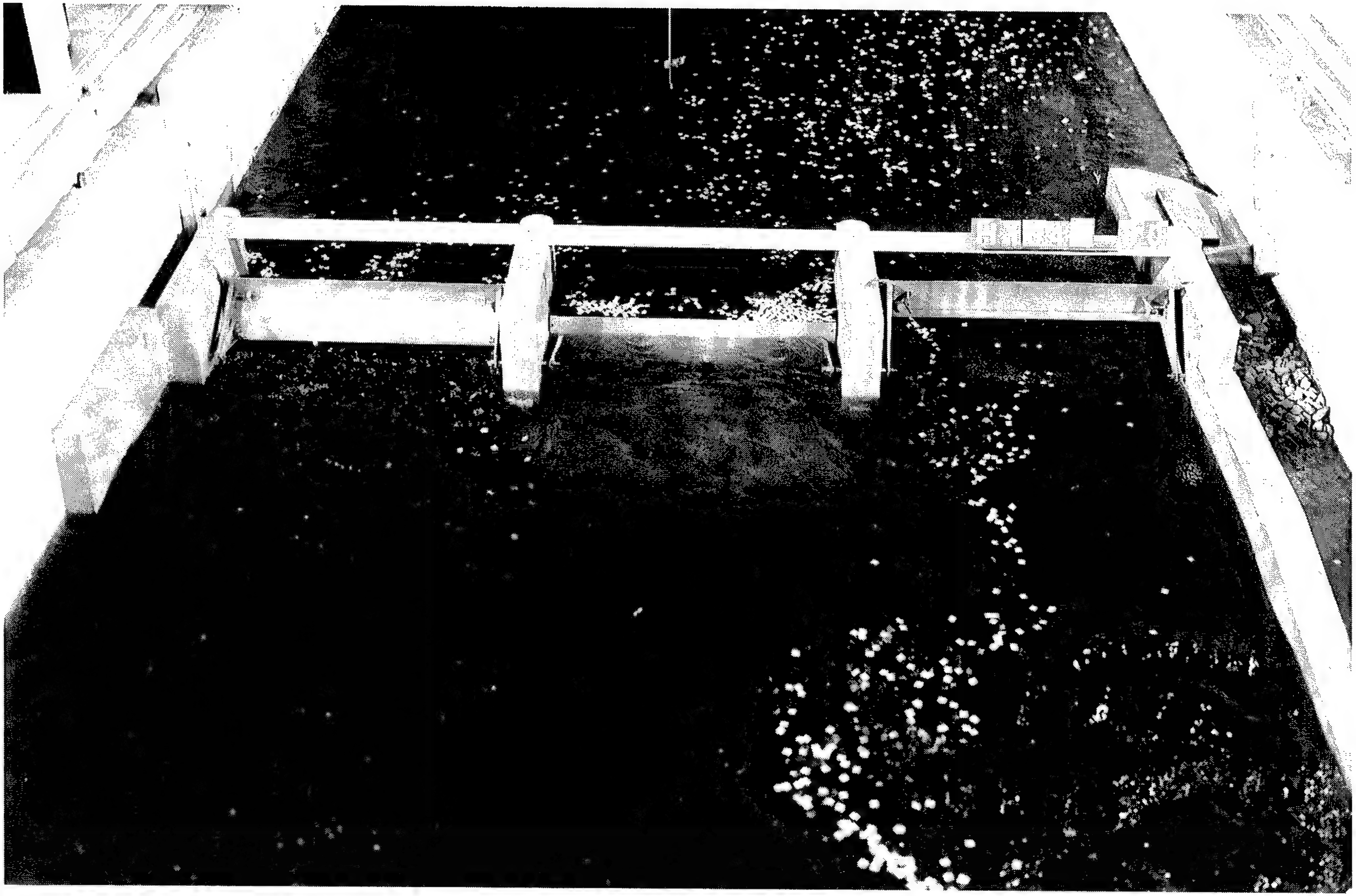


Photo 10. Type 2 riprap, Configuration 1; Q = 1,078 cu m/sec (38,500 cfs); G_2 = 3.6 m (12 ft), G_3 = 0, G_4 = full; pool el 743.5; tailwater el 736.3

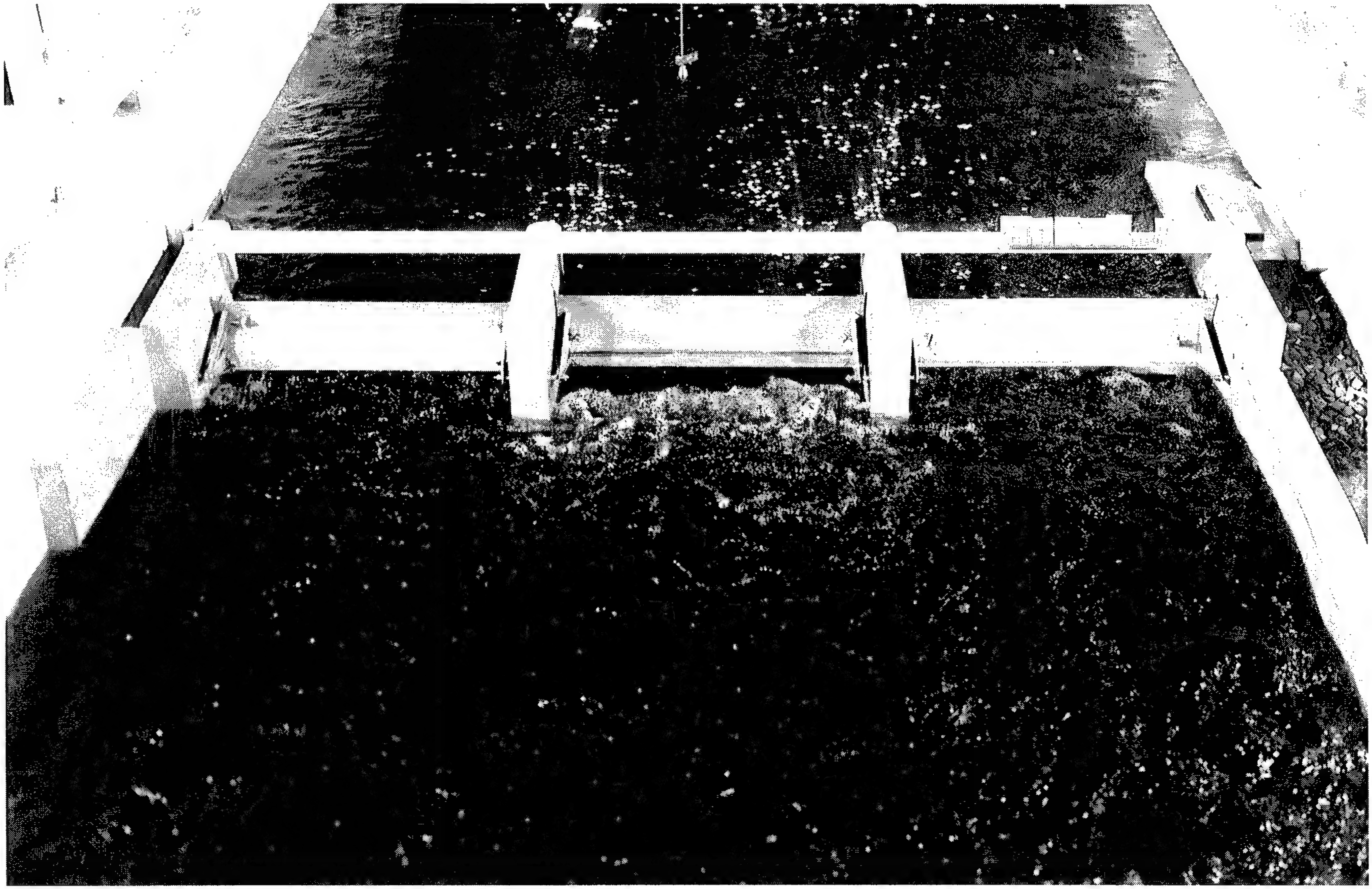


Photo 11. Type 2 riprap, Configuration 1; Q = 1,204 cu m/sec (42,600 cfs); G_2 = 2.4 m (8 ft), G_3 = 3.0 m (10 ft), G_4 = 2.4 m (8 ft); pool el 743.5; tailwater el 735.5

Photo 12. Type 2 riprap, Configuration 1; Q = 1,366 cu m/sec (48,800 cfs); G_2 = 3.0 m (10 ft), G_3 = 3.6 m (12 ft), G_4 = 3.0 m (10 ft); pool el 743.5; tailwater el 737.1

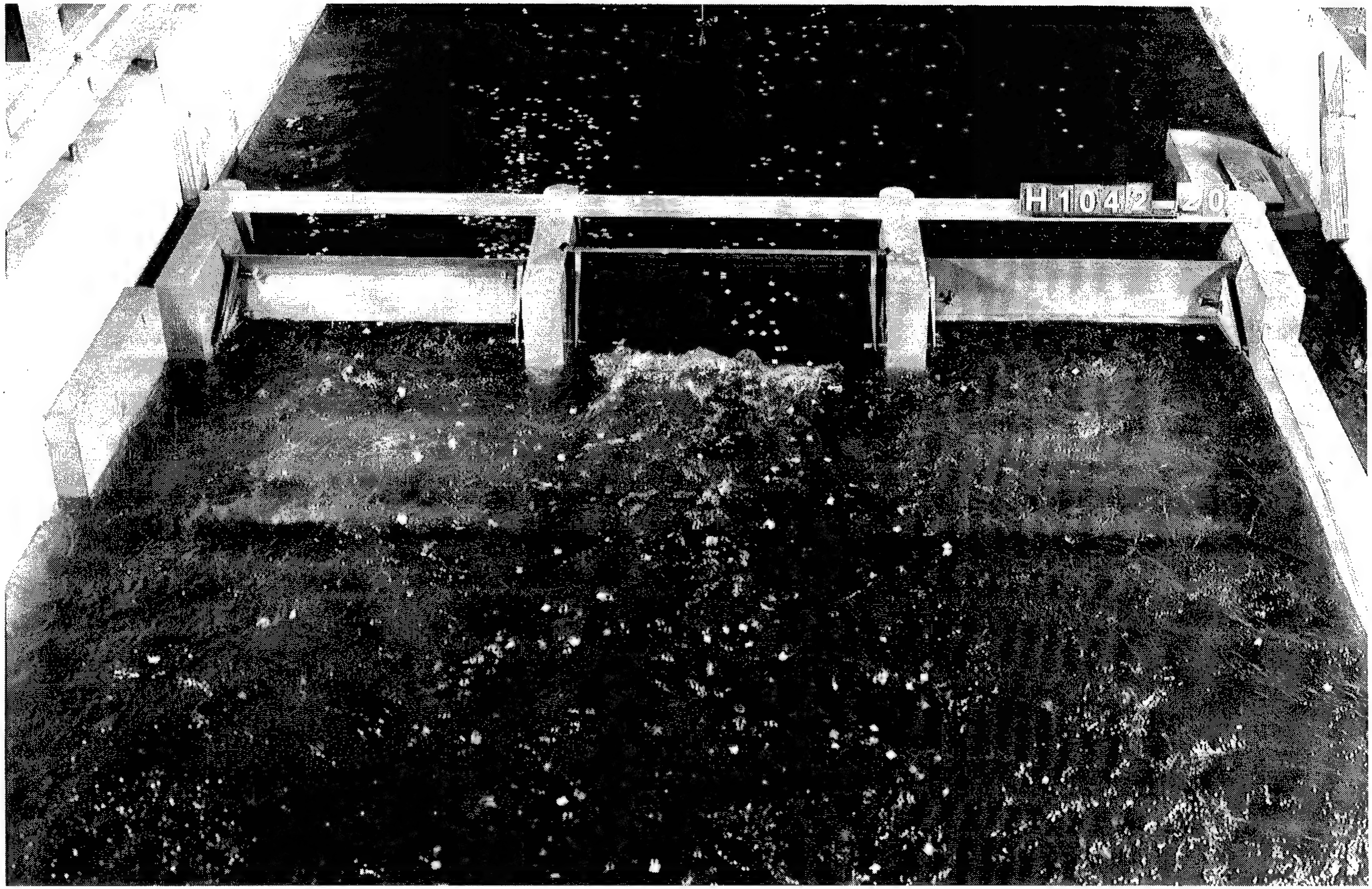


Photo 13. Type 2 riprap, Configuration 1; Q = 1,537 cu m/sec (54,900 cfs); G_2 = 3.6 m (12 ft), G_3 = Full, G_4 = 3.6 m (12 ft); pool el 743.5; tailwater el 739.0

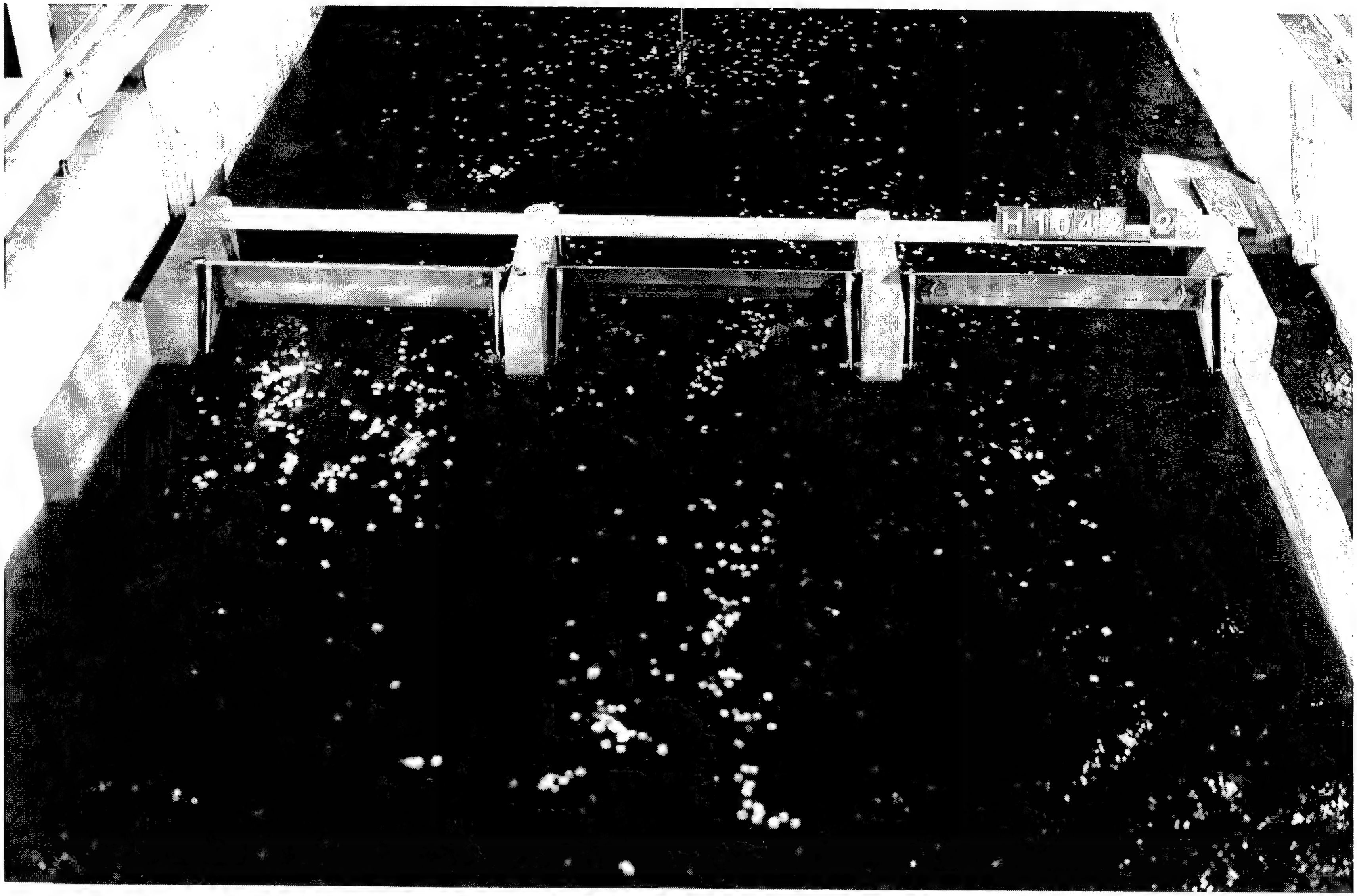


Photo 14. Type 2 riprap, Configuration 1; Q = 1,630 cu m/sec (58,200 cfs); G_2 = full, G_3 = full, G_4 = full; pool el 743.5; tailwater el 740.3

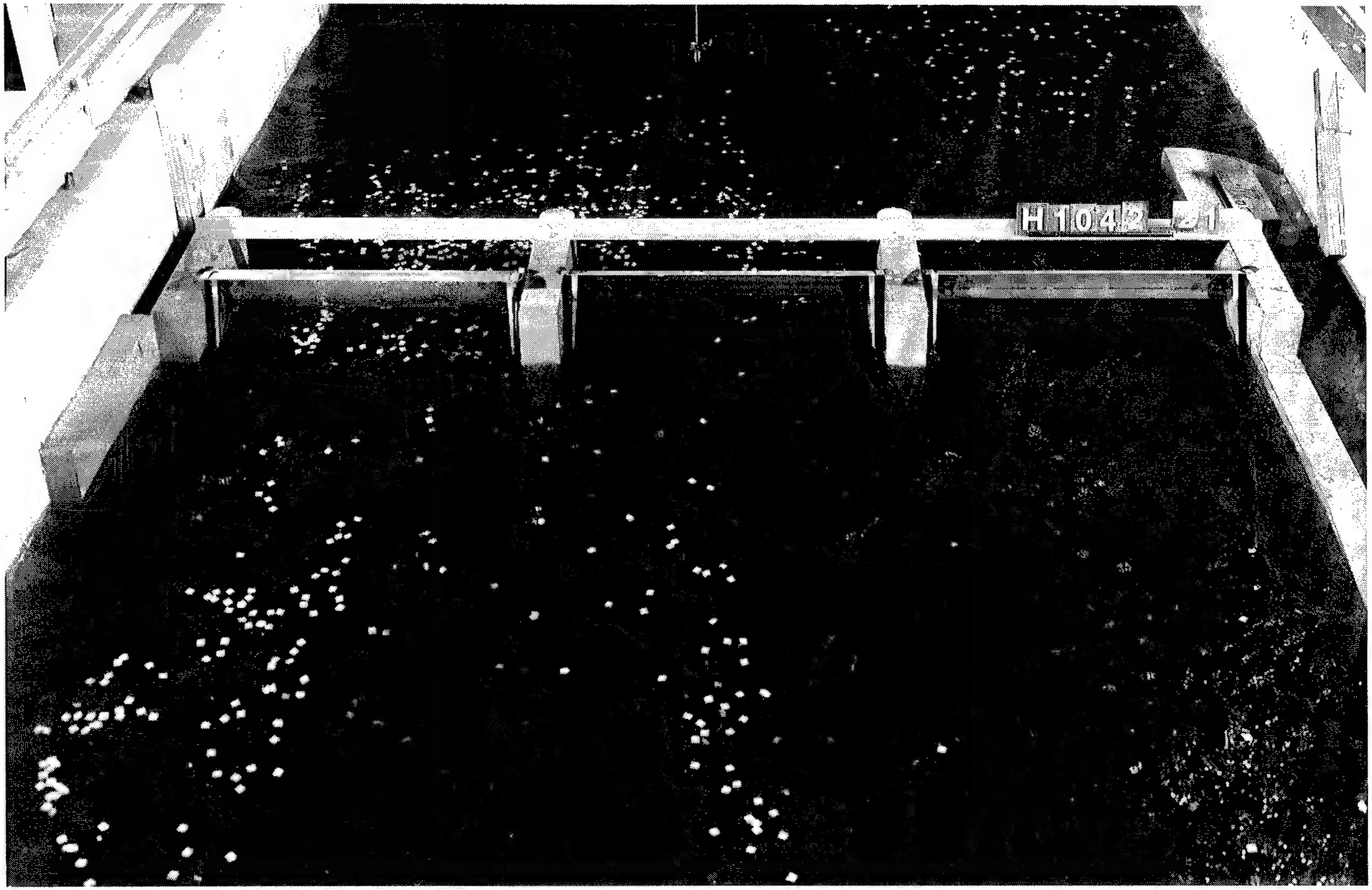


Photo 15. Type 2 riprap, Configuration 1; Q = 2,000 cu m/sec (73,800 cfs); G_2 = full, G_3 = full, G_4 = full; pool el 746.9; tailwater el 745.2

Photo 16. Type 3 riprap/rock apron, configuration 2; Q = 129 cu m/sec (4,600 cfs); G_3 = 0.6 m (2 ft), G_4 = 0, G_5 = 0; upper pool el 743.5; tailwater el 723.7

Photo 17. Type 3 riprap/rock apron, configuration 2; Q = 314 cu m/sec (11,200 cfs); G_3 = 0, G_4 = 0, G_5 = 1.8 m (6 ft); upper pool el 743.5; tailwater el 723.7

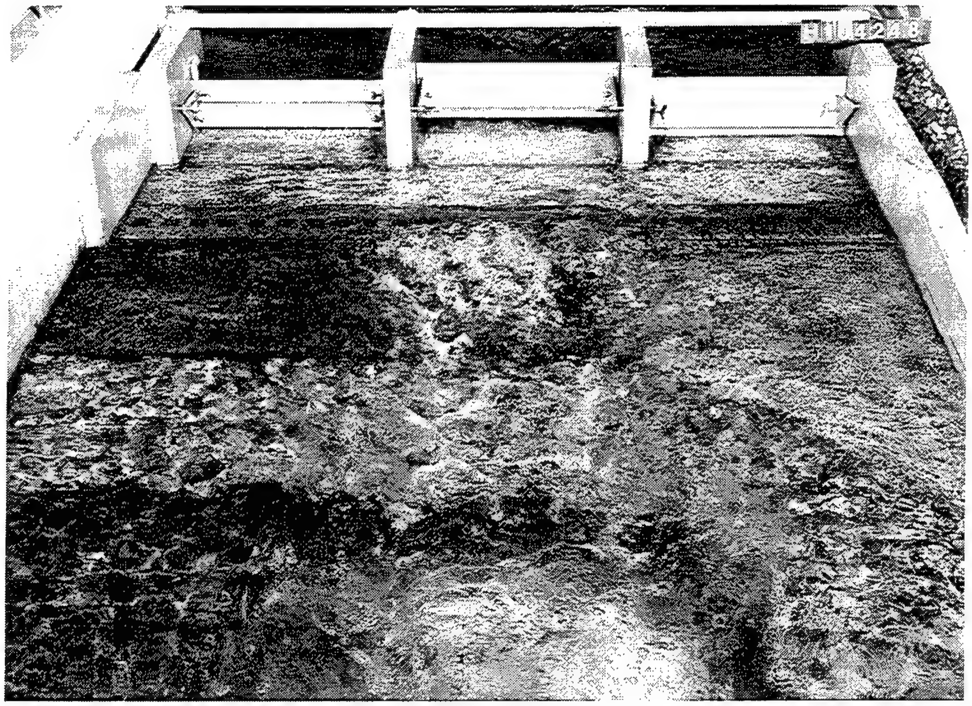


Photo 18. Type 3 riprap/rock apron, configuration 2; Q = 314 cu m/sec (11,200 cfs); G_3 = 0, G_4 = 1.8 m (6 ft), G_5 = 0; upper pool el 743.5; tailwater el 723.7

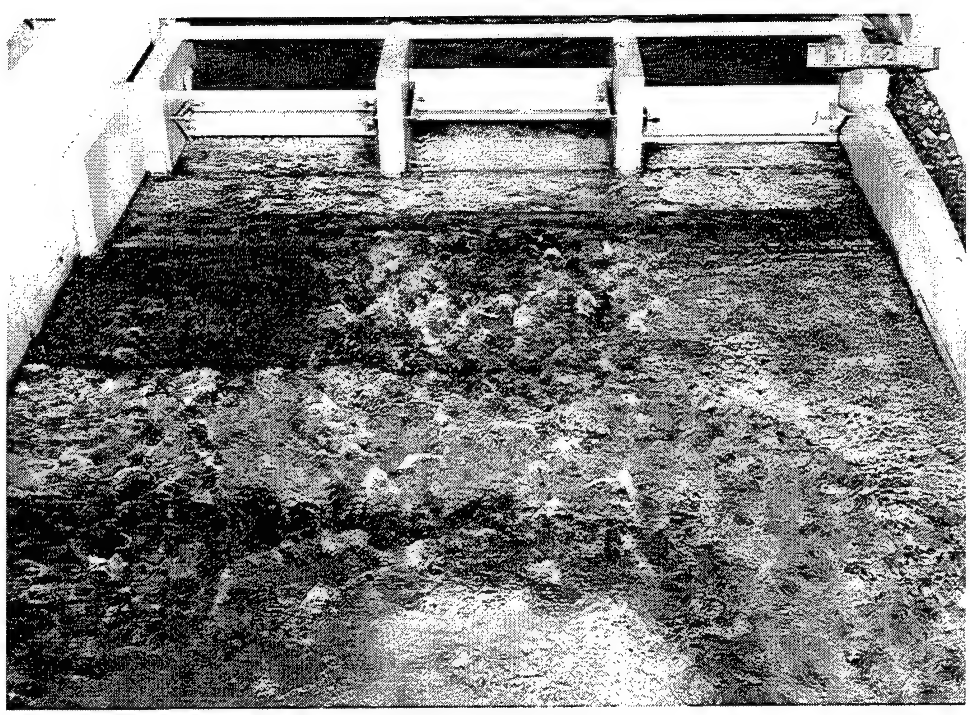


Photo 19. Type 3 riprap/rock apron, configuration 2; Q = 378 cu m/sec (13,500 cfs); G_3 = 0, G_4 = 2.4 m (8 ft), G_5 = 0; upper pool el 743.5; tailwater el 723.7

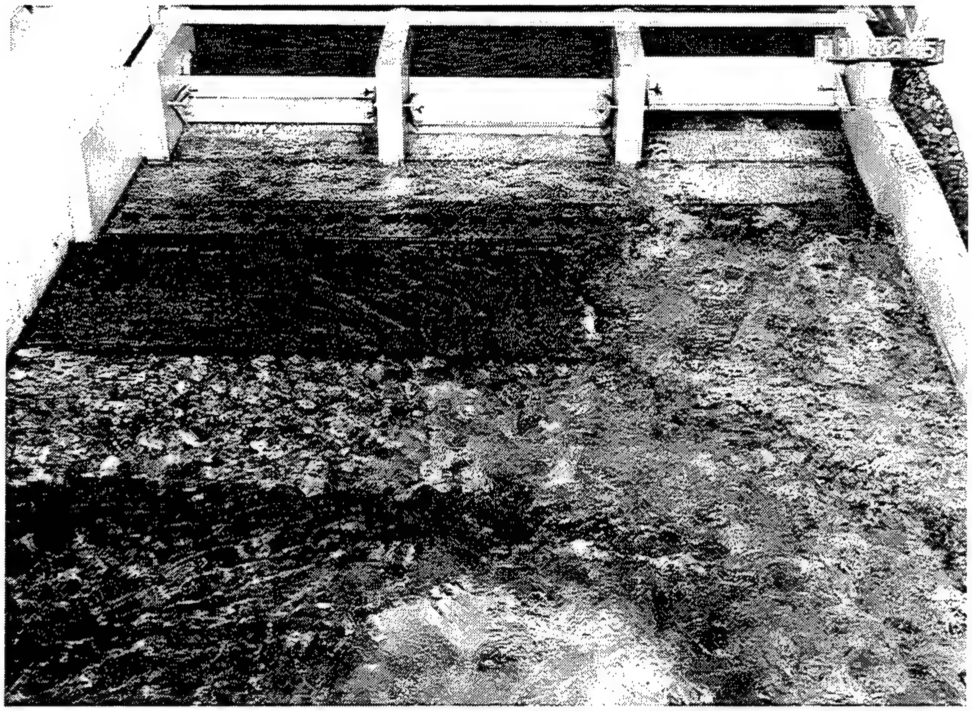


Photo 20. Type 3 riprap/rock apron, configuration 2; Q = 378 cu m/sec (13,500 cfs); $G_3 = 0$, $G_4 = 0$, $G_5 = 2.4$ m (8 ft); upper pool el 743.5; tailwater el 727.0

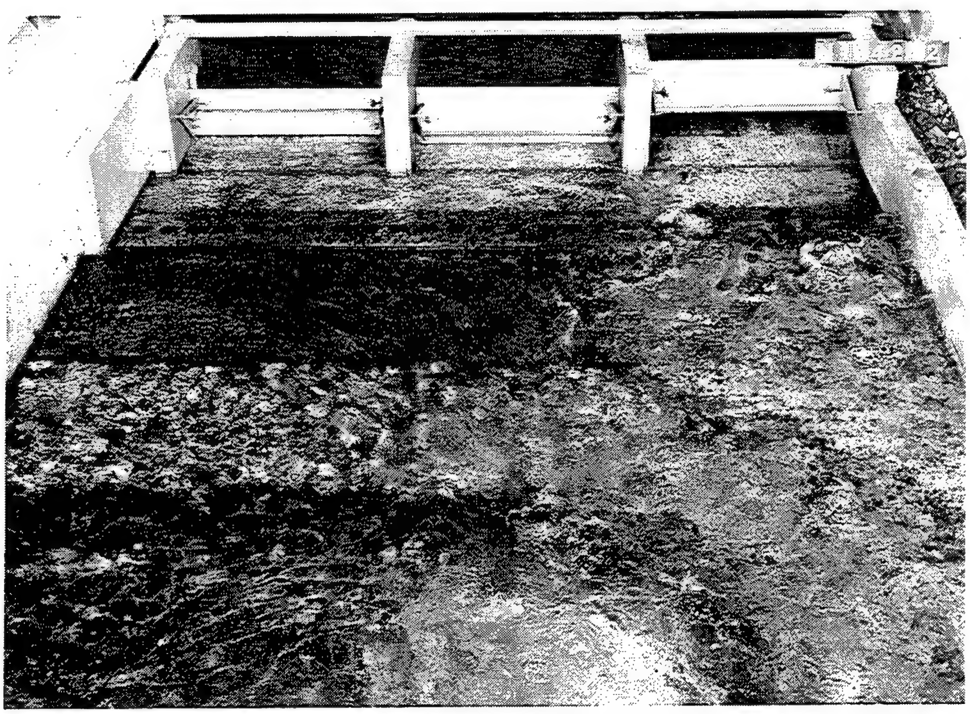


Photo 21. Type 3 riprap/rock apron, configuration 2; Q = 437 cu m/sec (15,600 cfs); $G_3 = 0$, $G_4 = 0$, $G_5 = 3.0$ m (10 ft); upper pool el 743.5; tailwater el 723.7

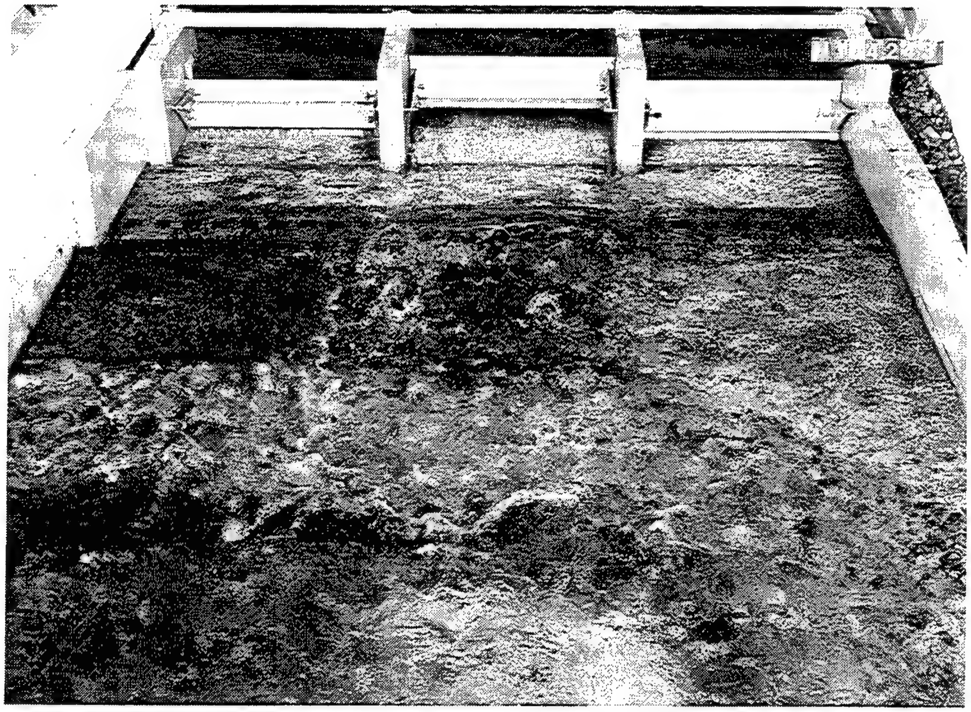


Photo 22. Type 3 riprap/rock apron, configuration 2; Q = 437 cu m/sec (15,600 cfs); G_3 = 0, G_4 = 3.0 m (10 ft), G_5 = 0; upper pool el 743.5; tailwater el 723.7

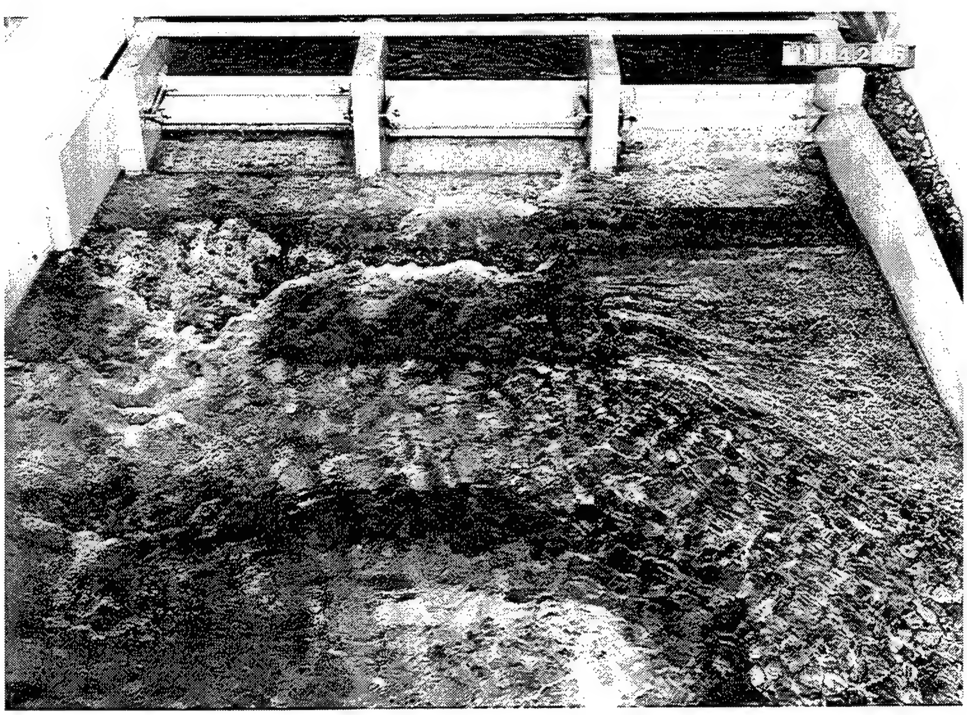


Photo 23. Type 3 riprap/rock apron, configuration 2; Q = 482 cu m/sec (17,200 cfs); G_3 = 1.2 m (4 ft), G_4 = 0.6 m, G_5 = 0.6 m (2 ft); upper pool el 743.5; tailwater el 726.8

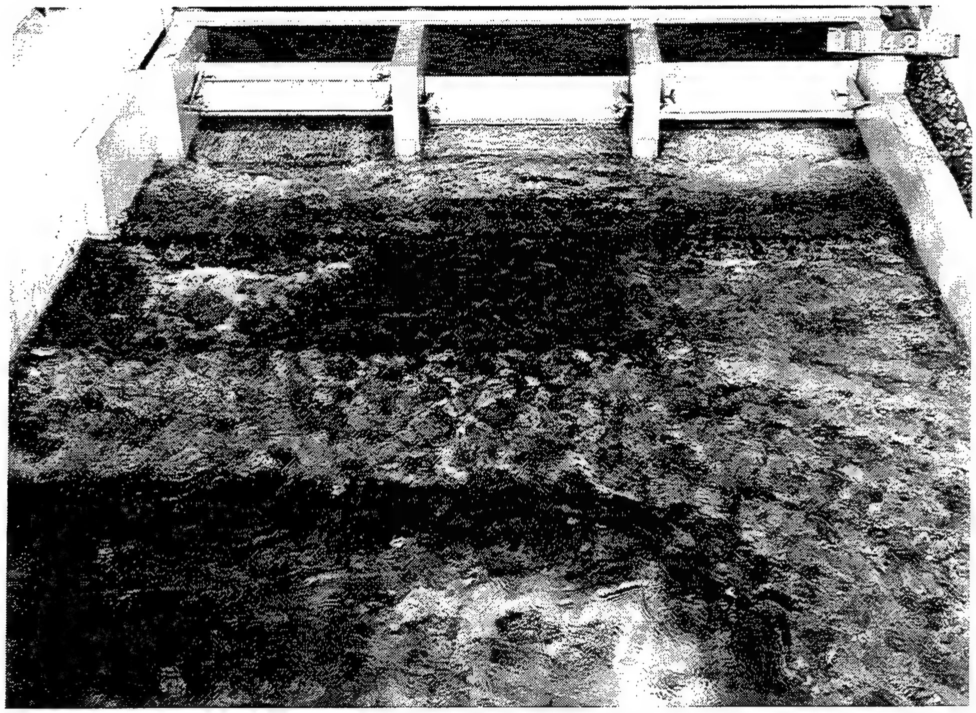


Photo 24. Type 3 riprap/rock apron, configuration 2; Q = 538 cu m/sec (19,200 cfs); G_3 = 1.8 m (6 ft), G_4 = 0, G_5 = 1.2 m (4 ft); upper pool el 743.5; tailwater el 728.9

Photo 25. Type 3 riprap/rock apron, configuration 2; Q = 574 cu m/sec (20,500 cfs); G_3 = 0, G_4 = 0, G_5 = full; upper pool el 743.5; tailwater el 729.0

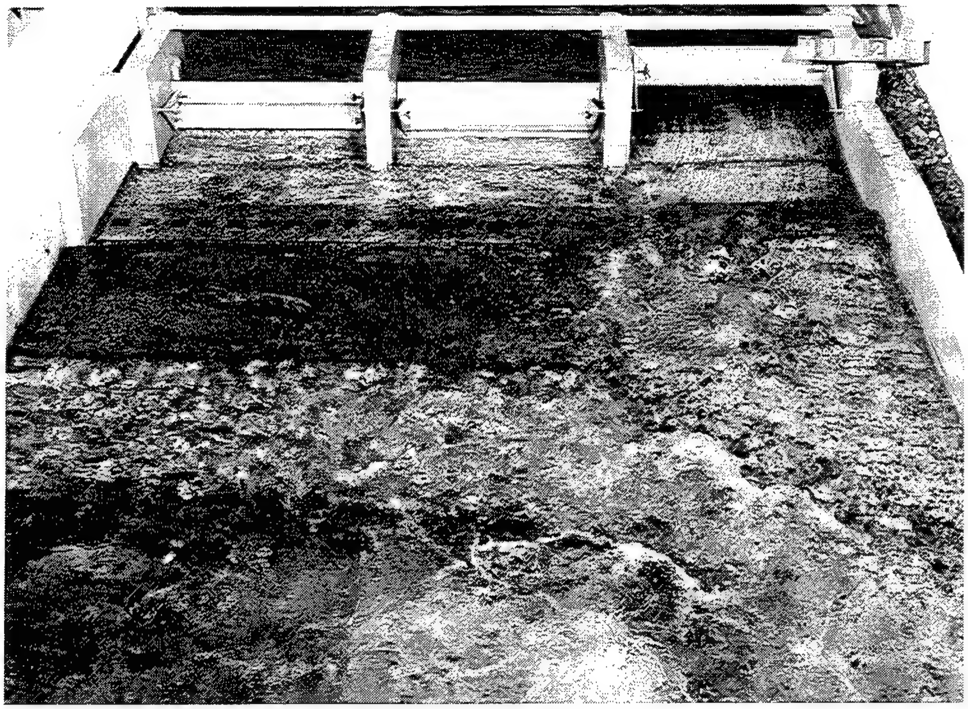


Photo 26. Type 3 riprap/rock apron, configuration 2; Q = 574 cu m/sec (20,500 cfs); $G_3 = 0$, $G_4 = 0$, $G_5 =$ full; upper pool el 743.5; tailwater el 723.7

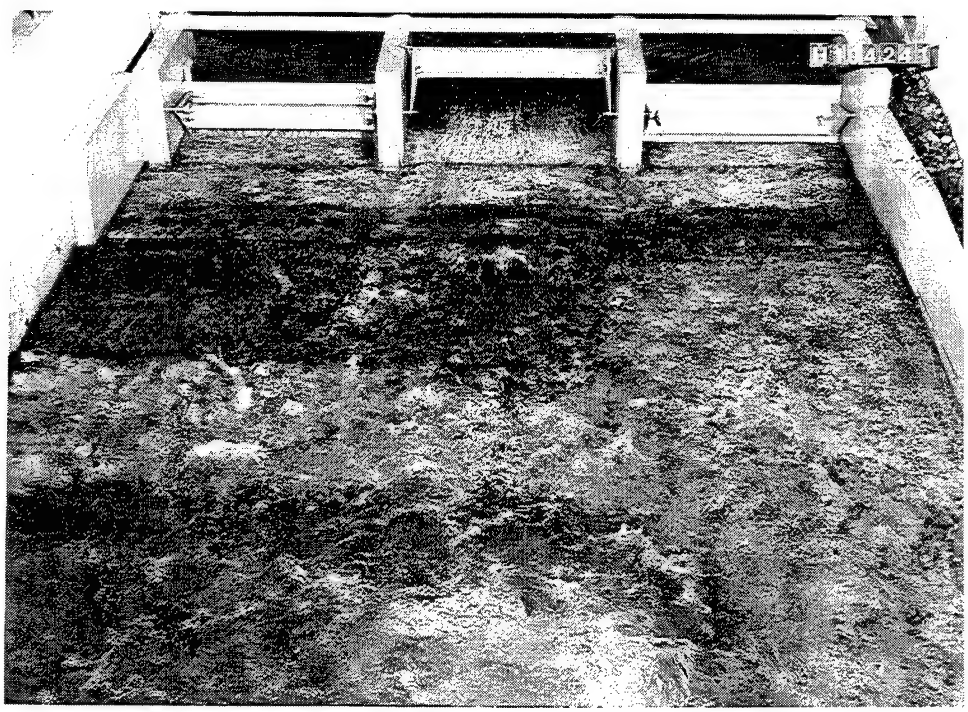


Photo 27. Type 3 riprap/rock apron, configuration 2; Q = 574 cu m/sec (20,500 cfs); $G_3 = 0$, $G_4 =$ full, $G_5 = 0$; upper pool el 743.5; tailwater el 723.7

Photo 28. Type 3 riprap/rock apron, configuration 2; Q = 762 cu m/sec (27,200 cfs); G_3 = 1.8 m (6 ft), G_4 = 1.2 m (4 ft), G_5 = 1.2 m; upper pool el 743.5; tailwater el 730.6

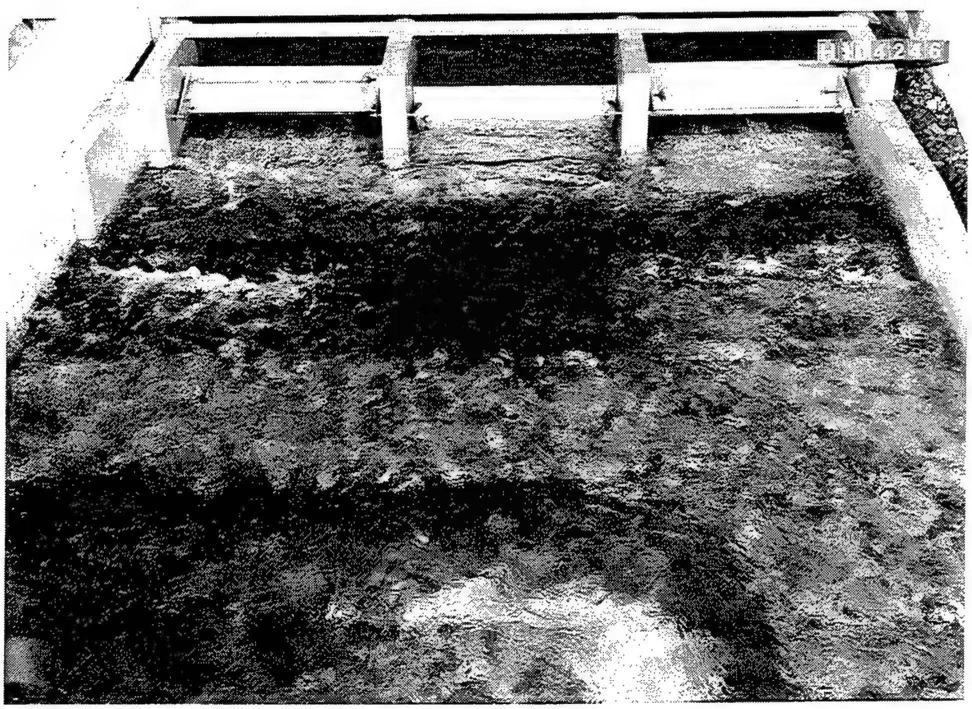


Photo 29. Type 3 riprap/rock apron, configuration 2; Q = 815 cu m/sec (29,100 cfs); G_3 = 3.0 (10 ft), G_4 = 0, G_5 = 2.4 m (8 ft); upper pool el 743.5; tailwater el 733.1

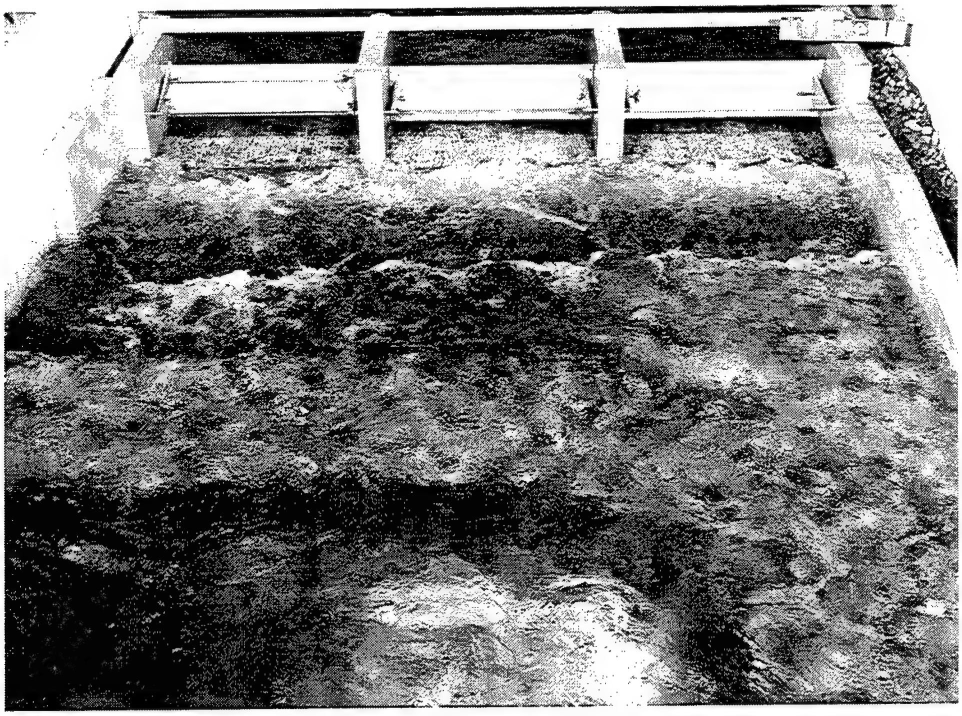


Photo 30. Type 3 riprap/rock apron, configuration 2; Q = 1,005 cu m/sec (35,900 cfs); G_3 = 2.4 m (8 ft), G_4 = 1.8 m (6 ft), G_5 = 1.8 m; upper pool el 743.5; tailwater el 733.5

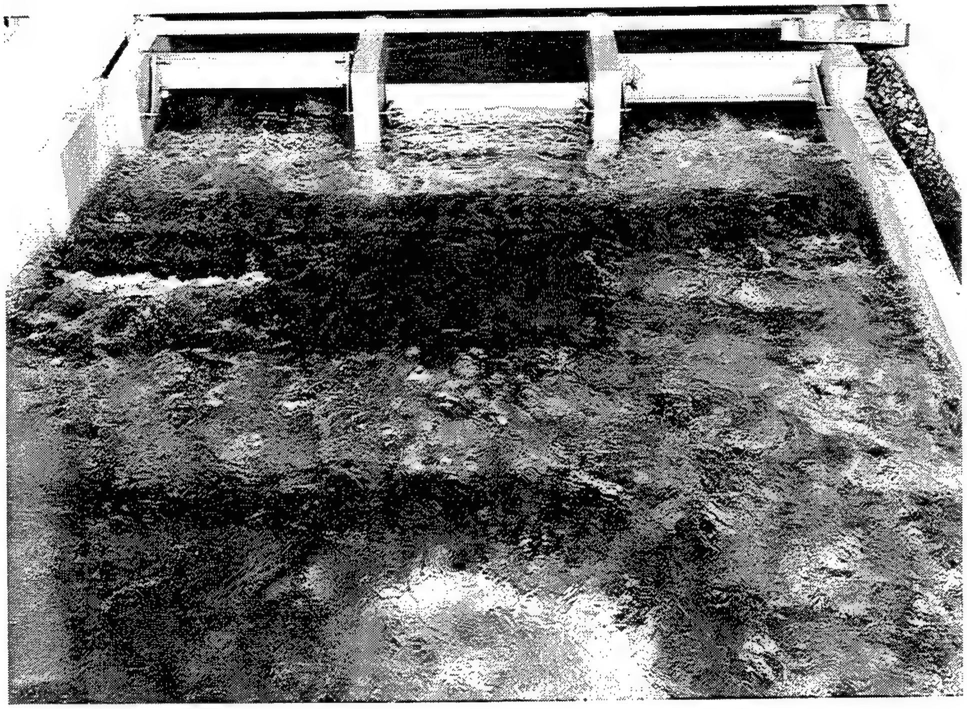


Photo 31. Type 3 riprap/rock apron, configuration 2; Q = 1,078 cu m/sec (38,500 cfs); G_3 = full, G_4 = 0, G_5 = 3.6 m (12 ft); upper pool el 743.5; tailwater el 736.3

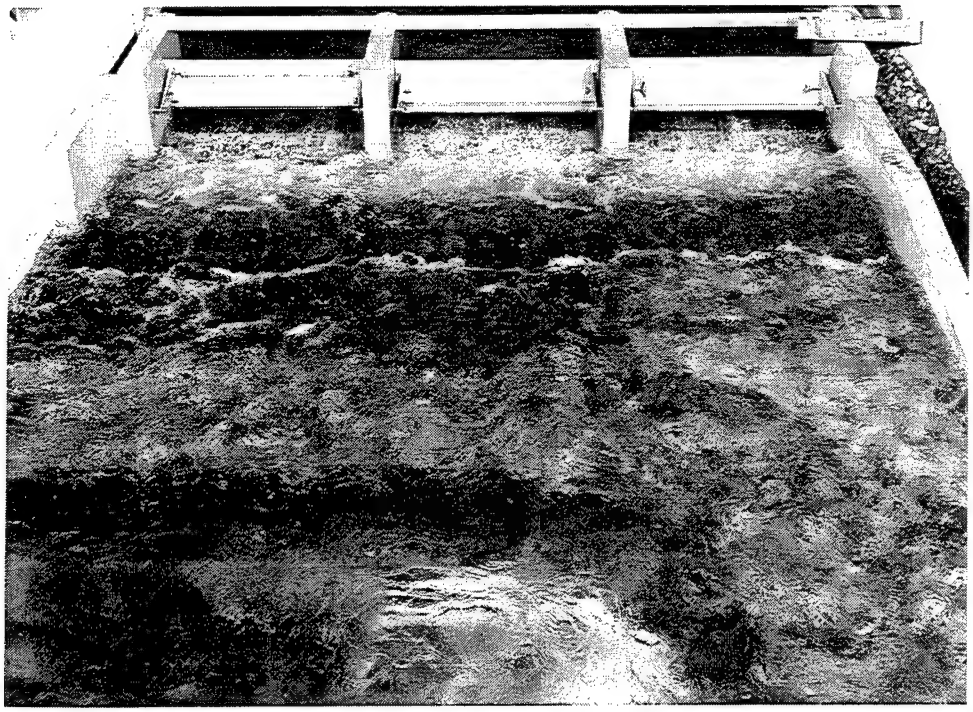


Photo 32. Type 3 riprap/rock apron, configuration 2; Q = 1,193 cu m/sec (42,600 cfs); G_3 = 3.0 m (10 ft), G_4 = 2.4 m (8 ft), G_5 = 2.4 m; upper pool el 743.5; tailwater el 735.5

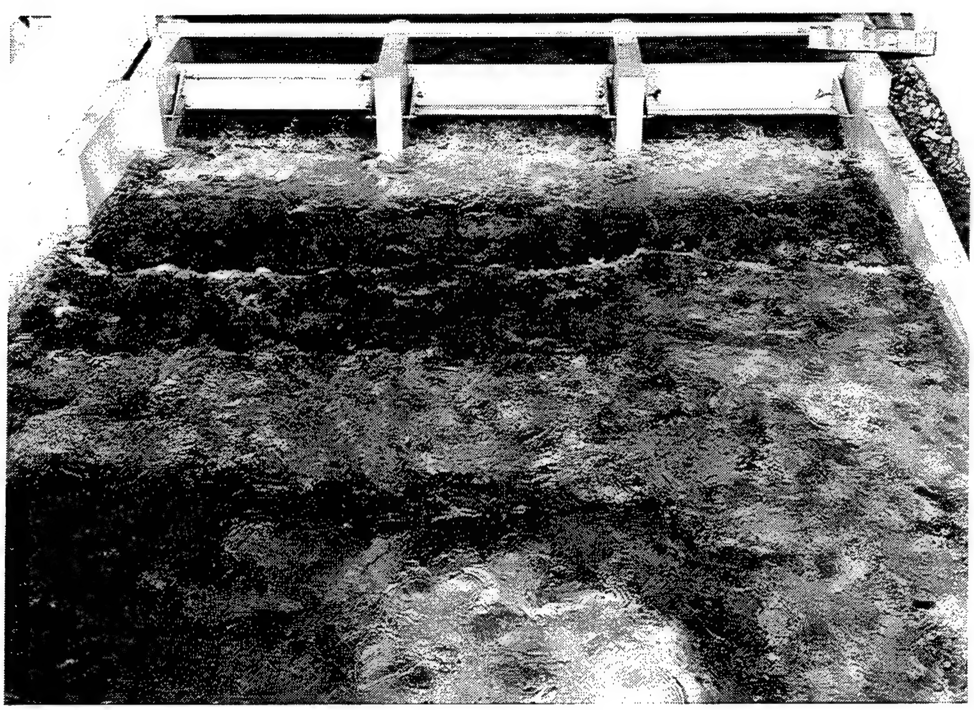


Photo 33. Type 3 riprap/rock apron, configuration 2; Q = 1,366 cu m/sec (48,800 cfs); G_3 = 3.6 m (12 ft), G_4 = 3.0 m (10 ft) , G_5 = 3.0 m (10 ft); upper pool el 743.5; tailwater el 737.1

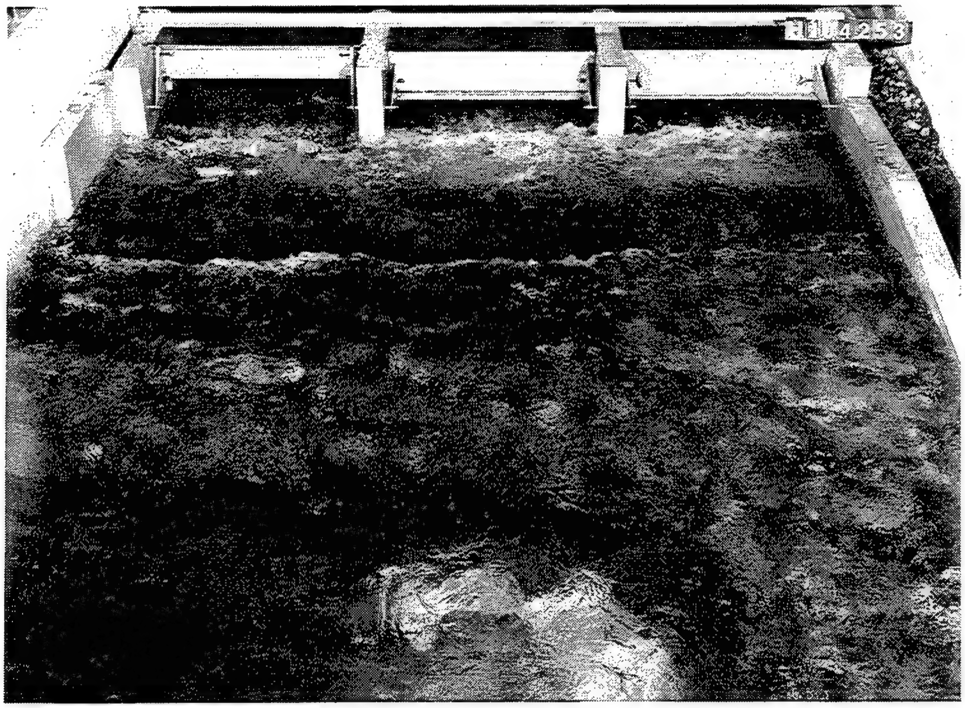


Photo 34. Type 3 riprap/rock apron, configuration 2; Q = 1,537 cu m/sec (54,900 cfs); G_3 = full, G_4 = 3.6 m (12 ft) , G_5 = 3.6 m (12 ft); upper pool el 743.5; tailwater el 739.0

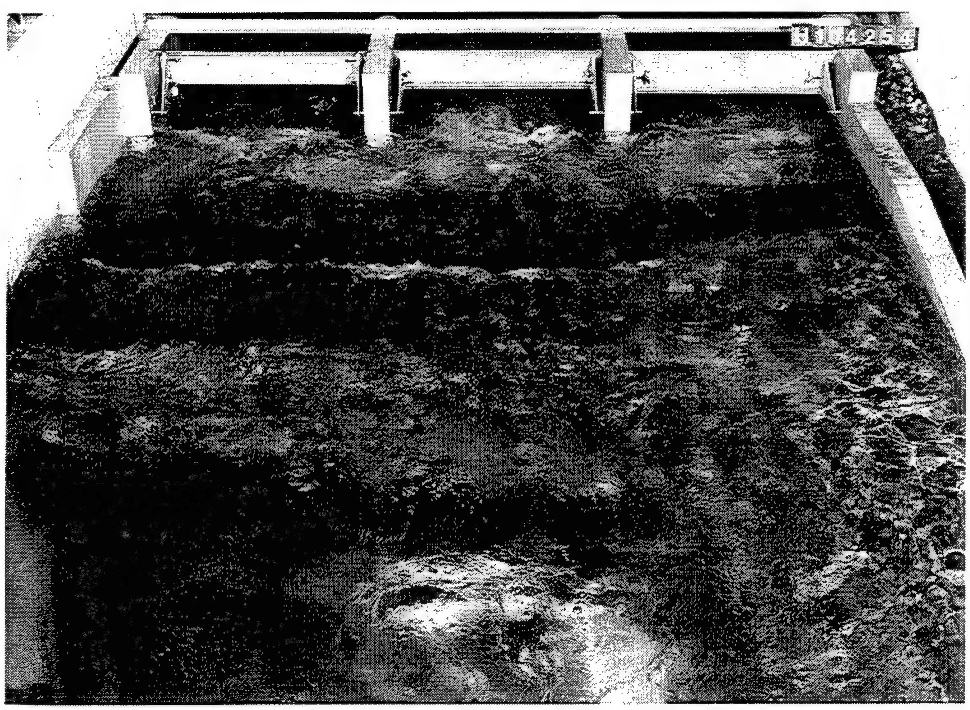
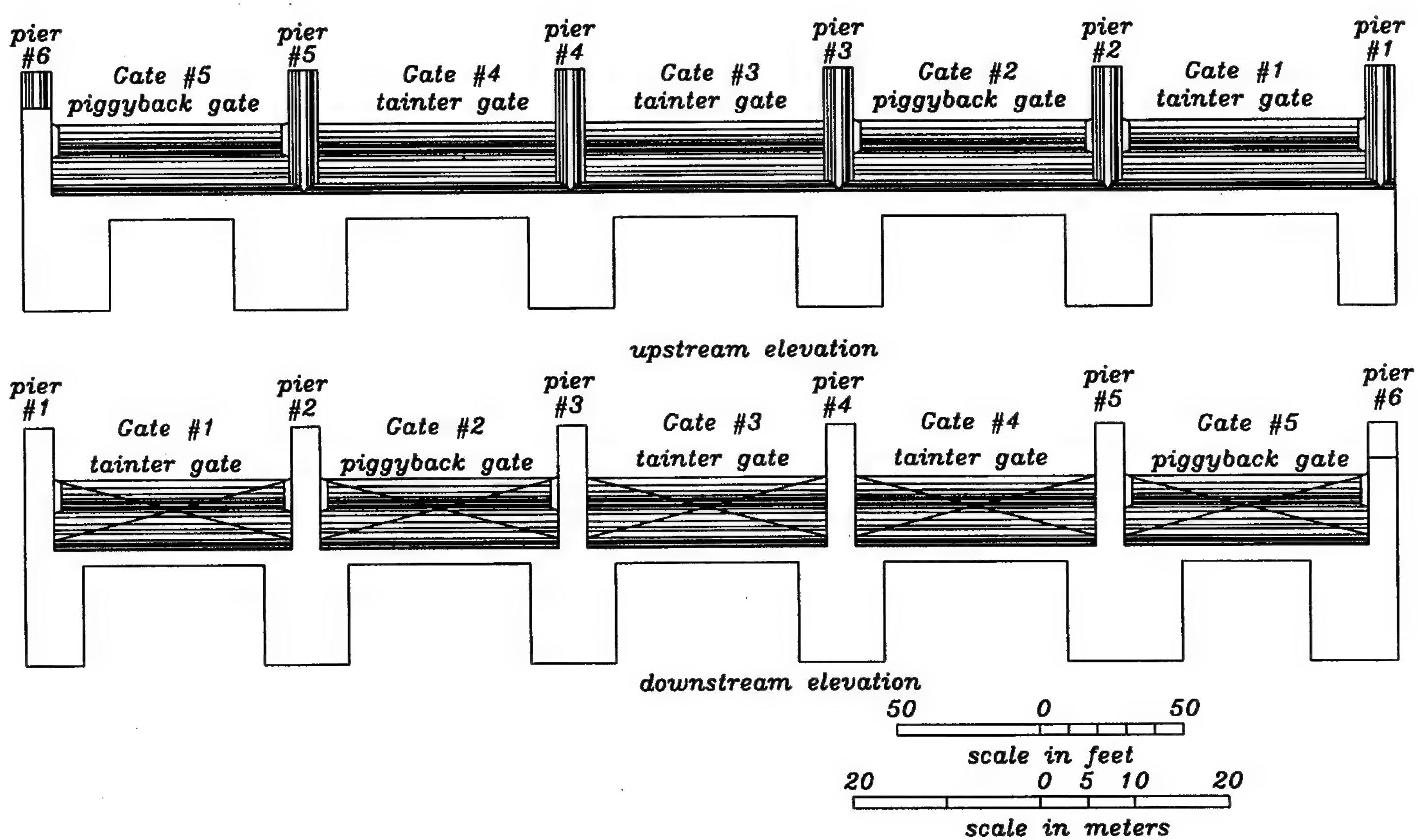
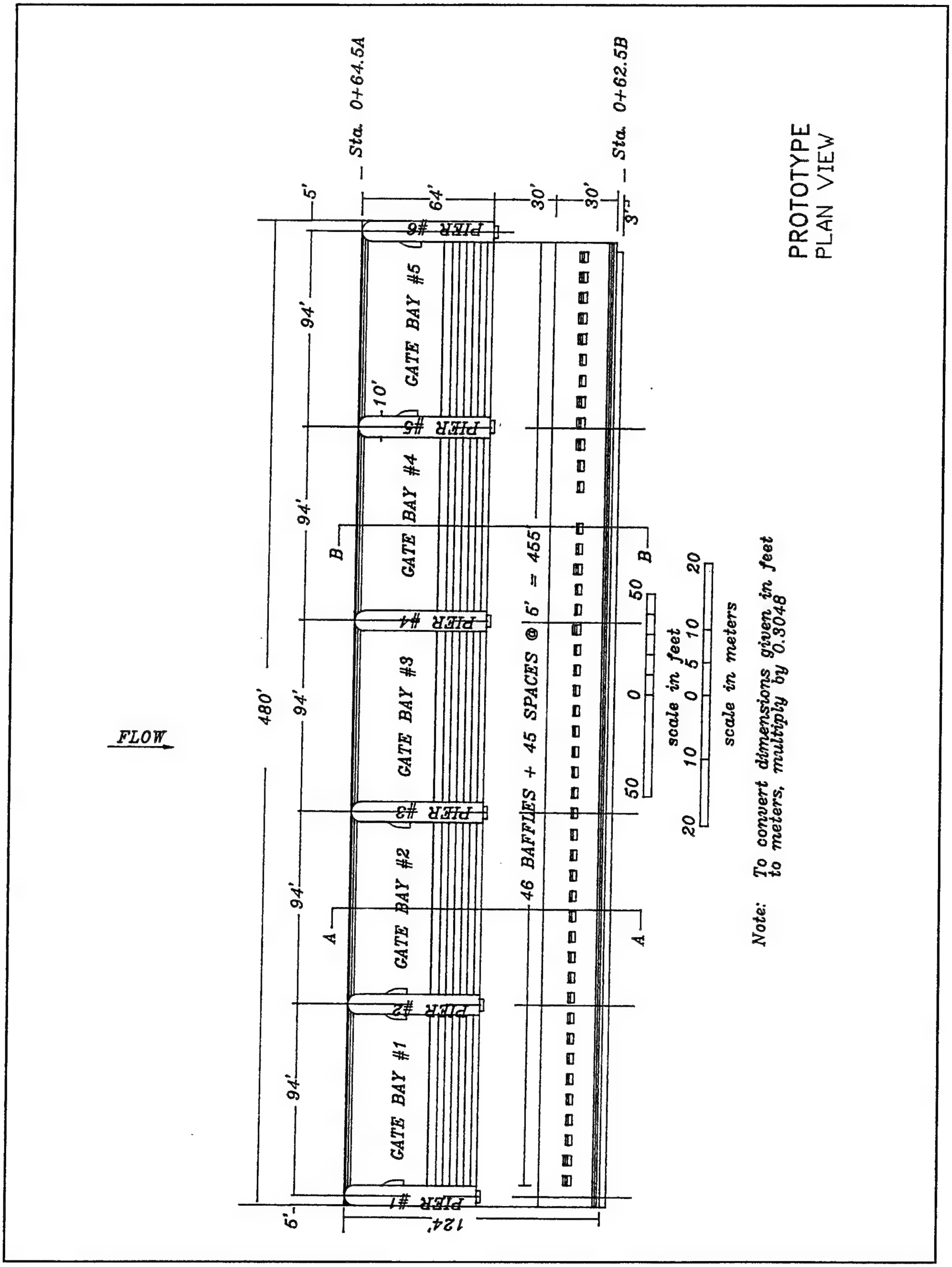


Photo 35. Type 3 riprap/rock apron, configuration 2; Q = 2,066 cu m/sec (73,800 cfs); G_3 = full, G_4 = full, G_5 = full; upper pool el 746.9; tailwater el 745.2

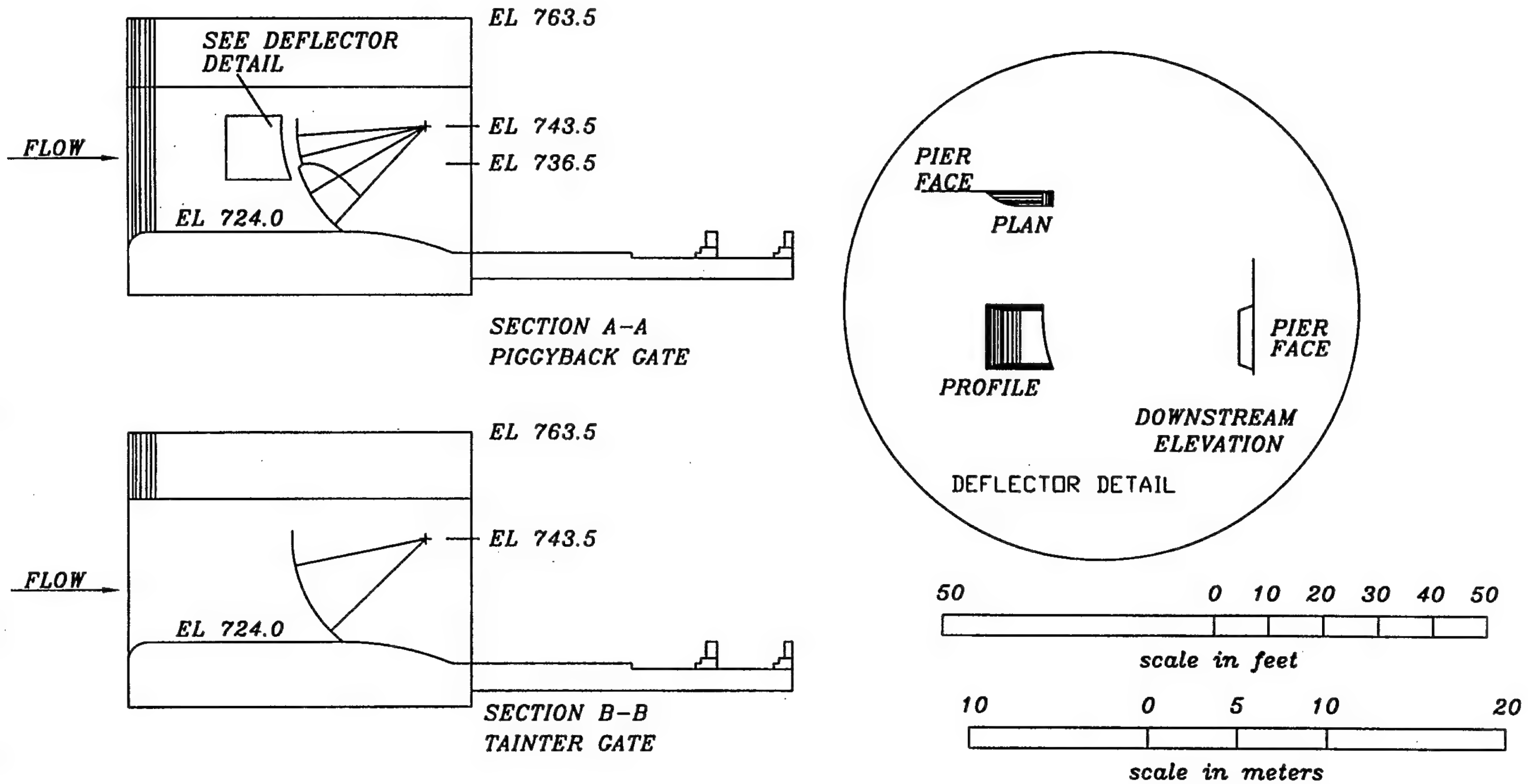


PROTOTYPE
ELEVATION VIEWS

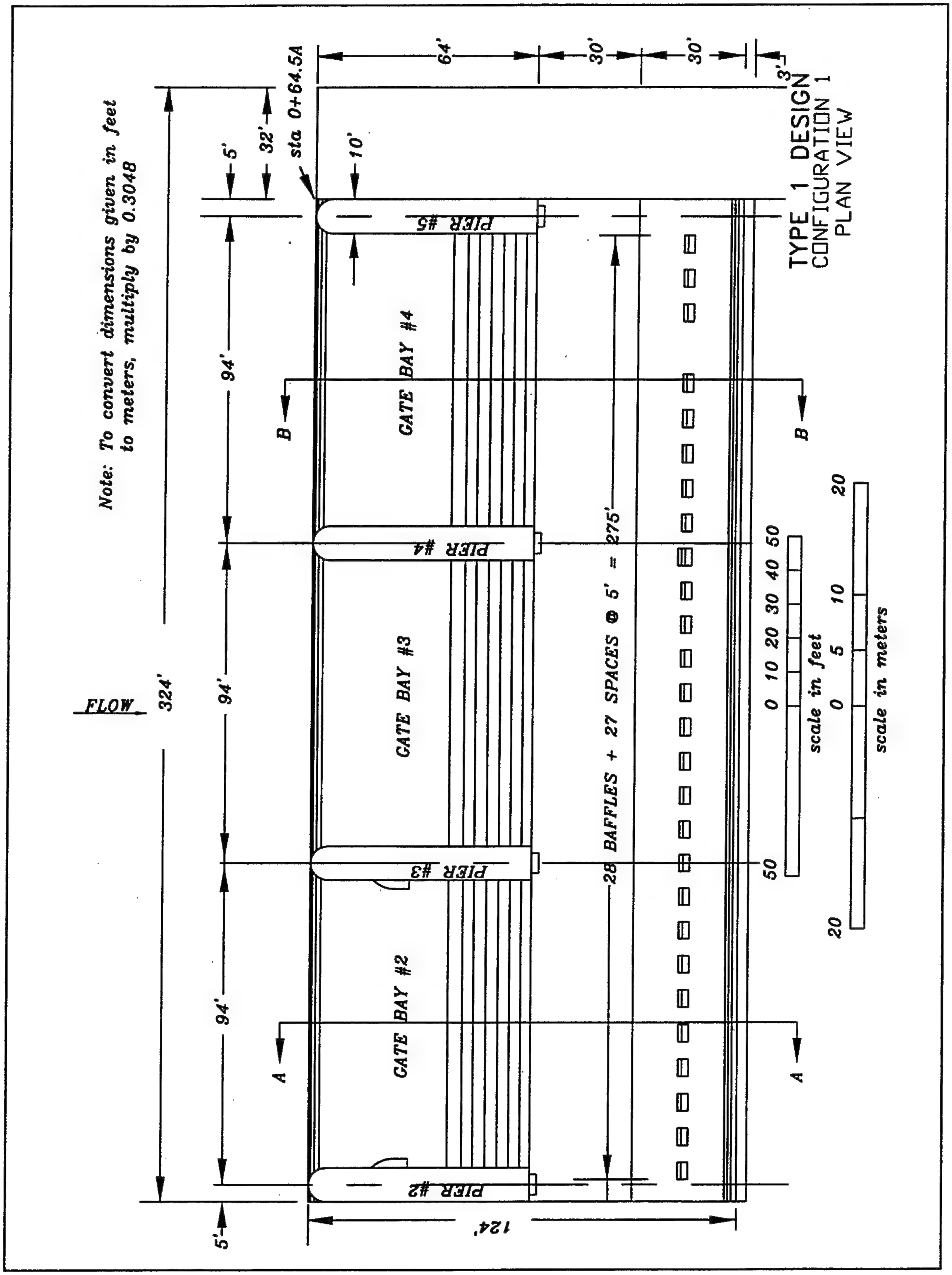


PROTOTYPE
PLAN VIEW

Plate 2



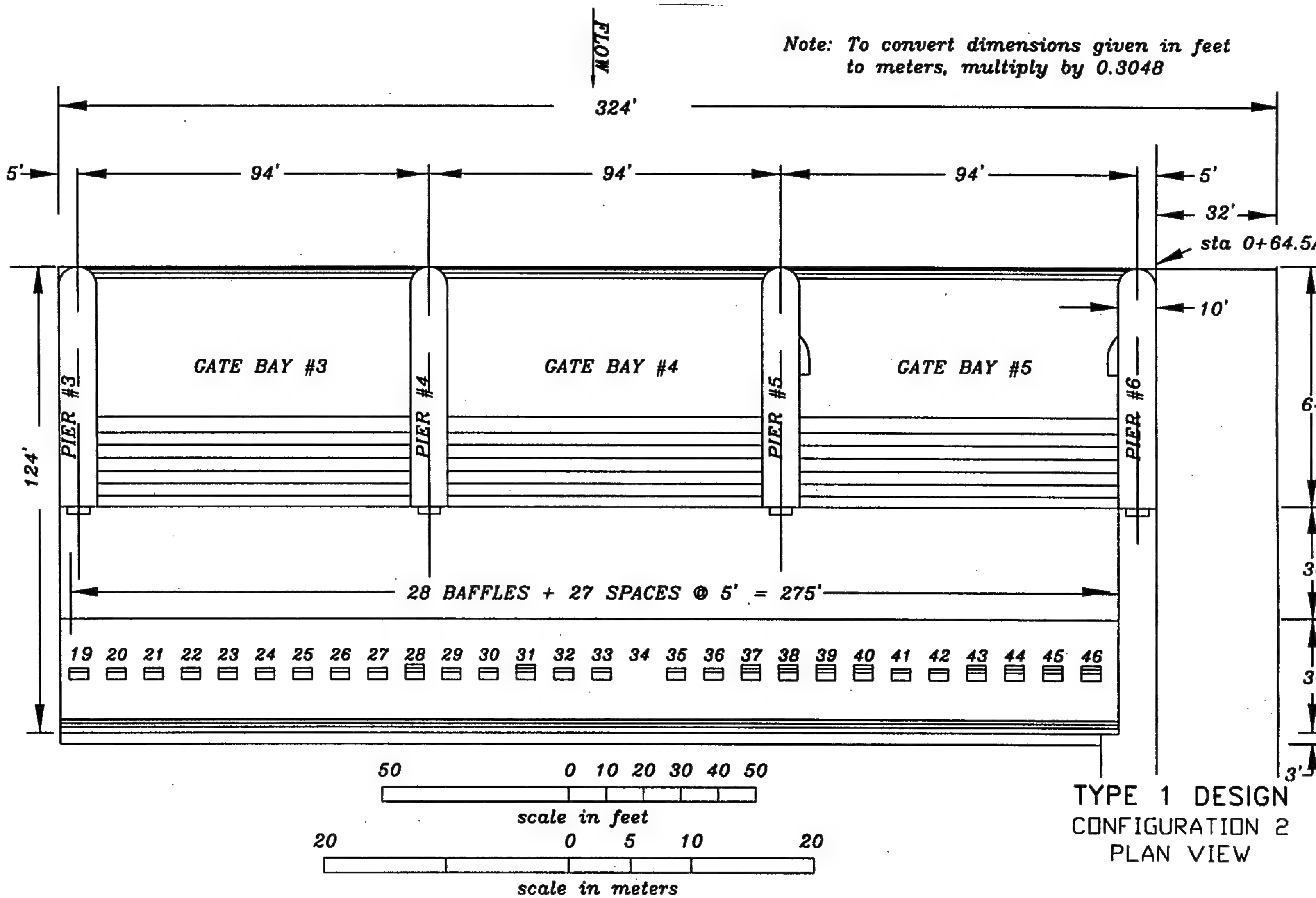
PROTOTYPE
SECTION VIEWS



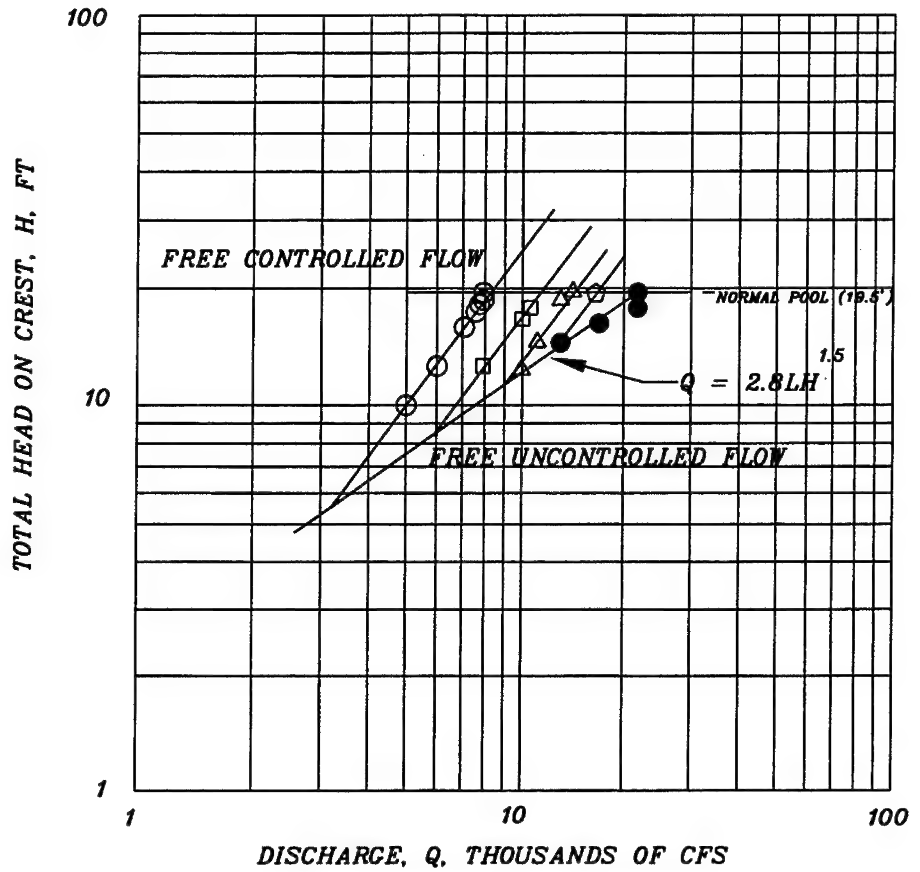
TYPE 1 DESIGN
CONFIGURATION 1
PLAN VIEW
Note: To convert dimensions given in feet to meters, multiply by 0.3048
FLOW
324'
94'
94'
94'
5'
32'
5'
10'
sta 0+64.5A
64'
30'
30'
3'
PIER #5
PIER #4
PIER #3
PIER #2
GATE BAY #4
GATE BAY #3
GATE BAY #2
B
B
A
A
28 BAFFLES + 27 SPACES @ 5' = 275'
124'
0 10 20 30 40 50
50
scale in feet
20 10 5 0
20
scale in meters

Plate 4

Note: To convert dimensions given in feet to meters, multiply by 0.3048



TYPE 1 DESIGN
CONFIGURATION 2
PLAN VIEW

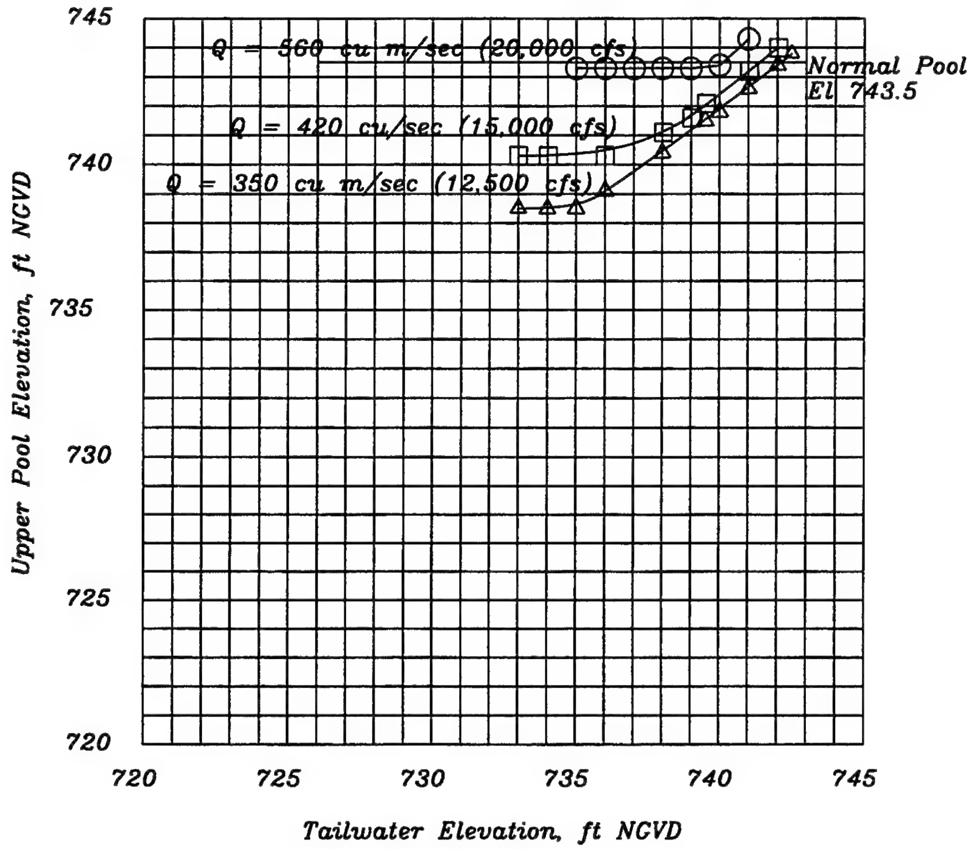


LEGEND

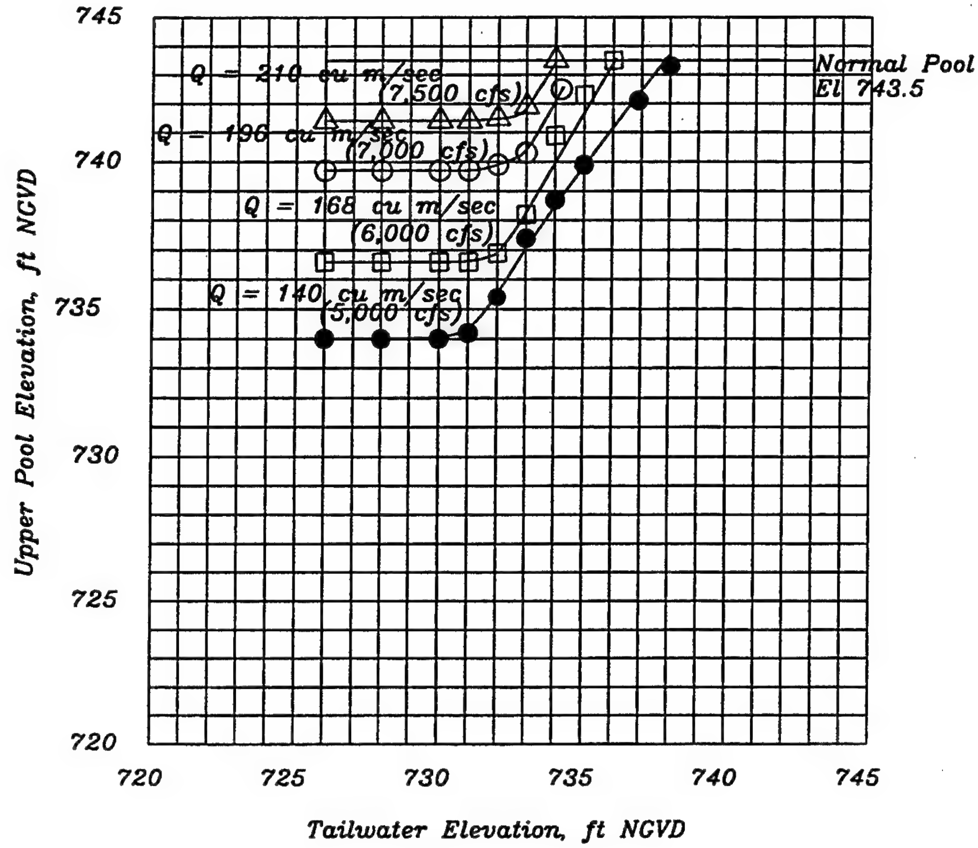
○ GATE OPEN 1.2 M (4.0 FT)
□ GATE OPEN 1.8 M (6.0 FT)
△ GATE OPEN 2.4 M (8.0 FT)
⬠ GATE OPEN 3.0 M (10.0 FT)
● UNCONTROLLED
L (ONE GATE BAY) = 25.6 M (84 FT)

Note: To convert head to meters, multiply by 0.3048.
To convert discharge to cubic meters per second, multiply by 0.028.

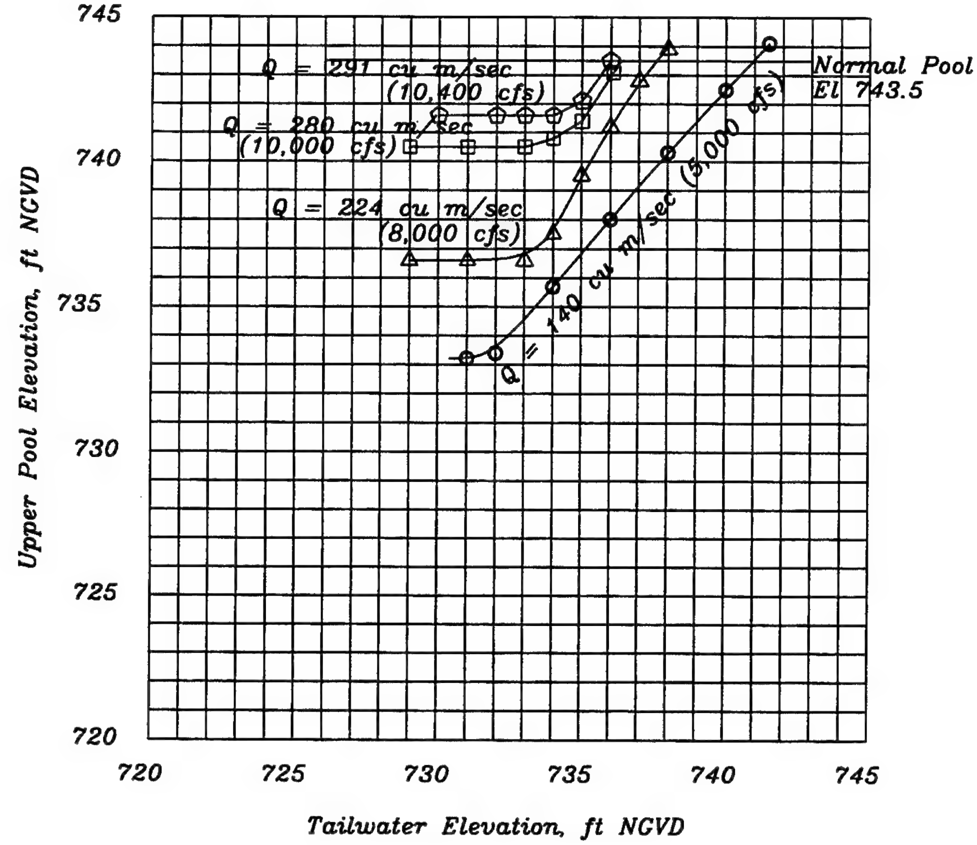
DISCHARGE–HEAD RELATIONSHIP FOR FREE FLOW
CREST ELEVATION 724.0



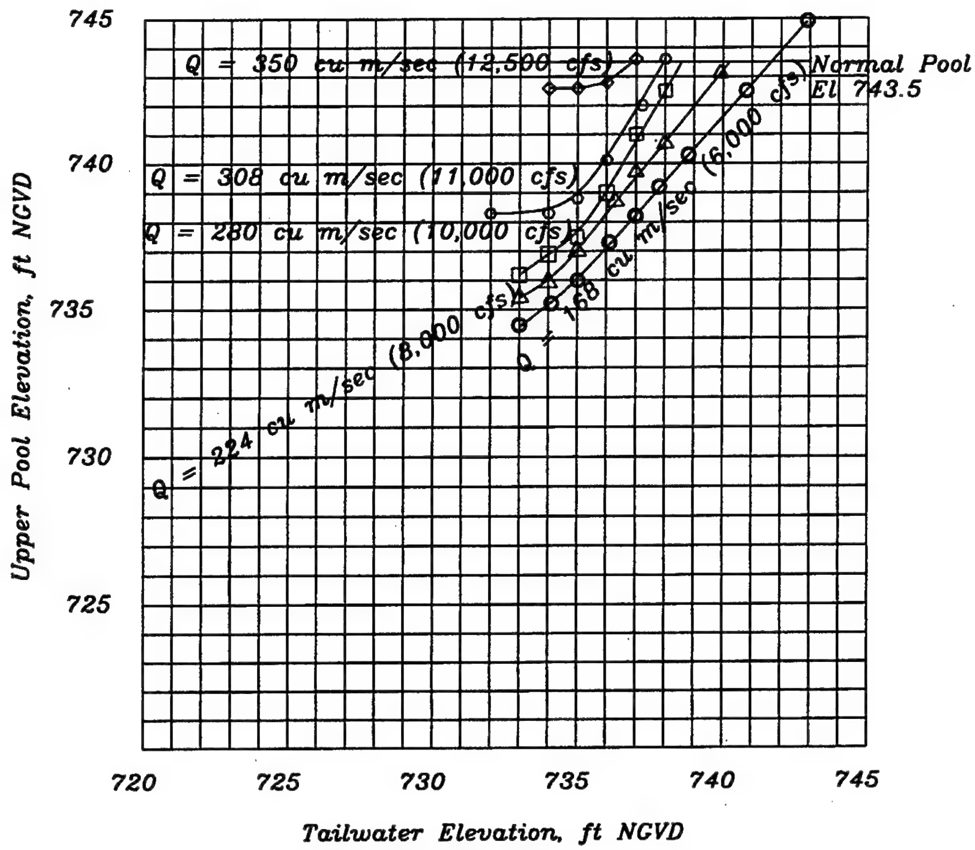
CALIBRATION DATA
FOR UNCONTROLLED FLOW
CREST ELEVATION 724.0



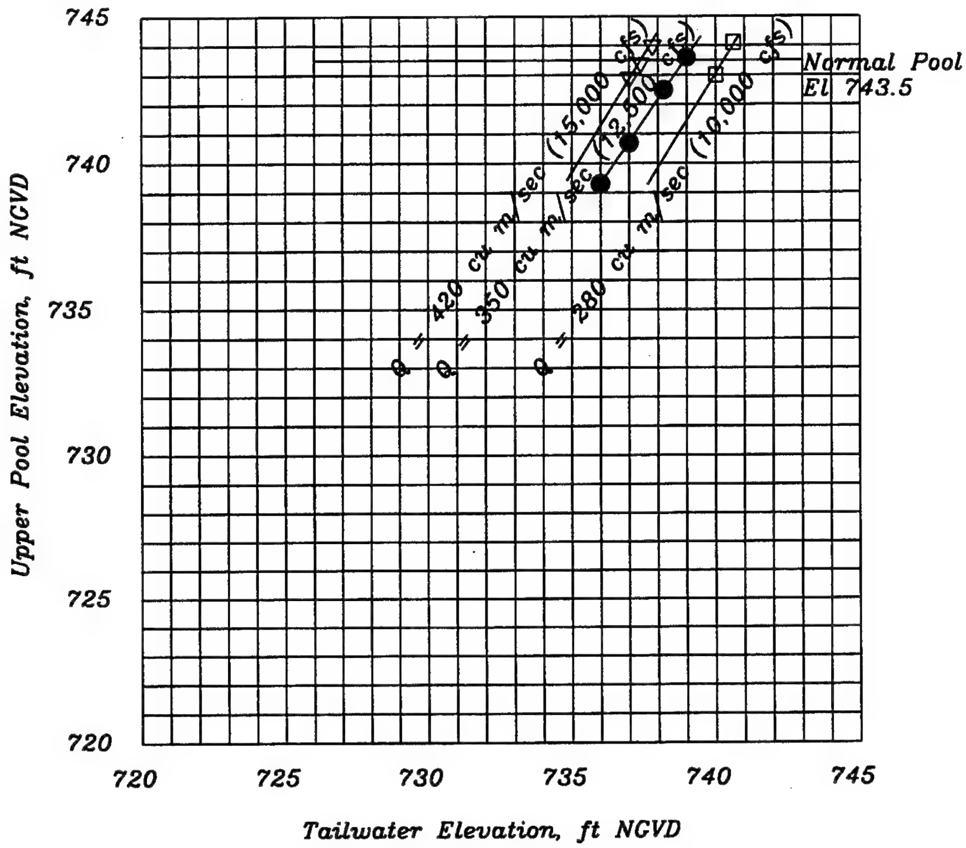
CALIBRATION DATA
FOR CONTROLLED FLOW
CREST ELEVATION 724.0
GATE OPENING 1.2 M (4.0 FT)



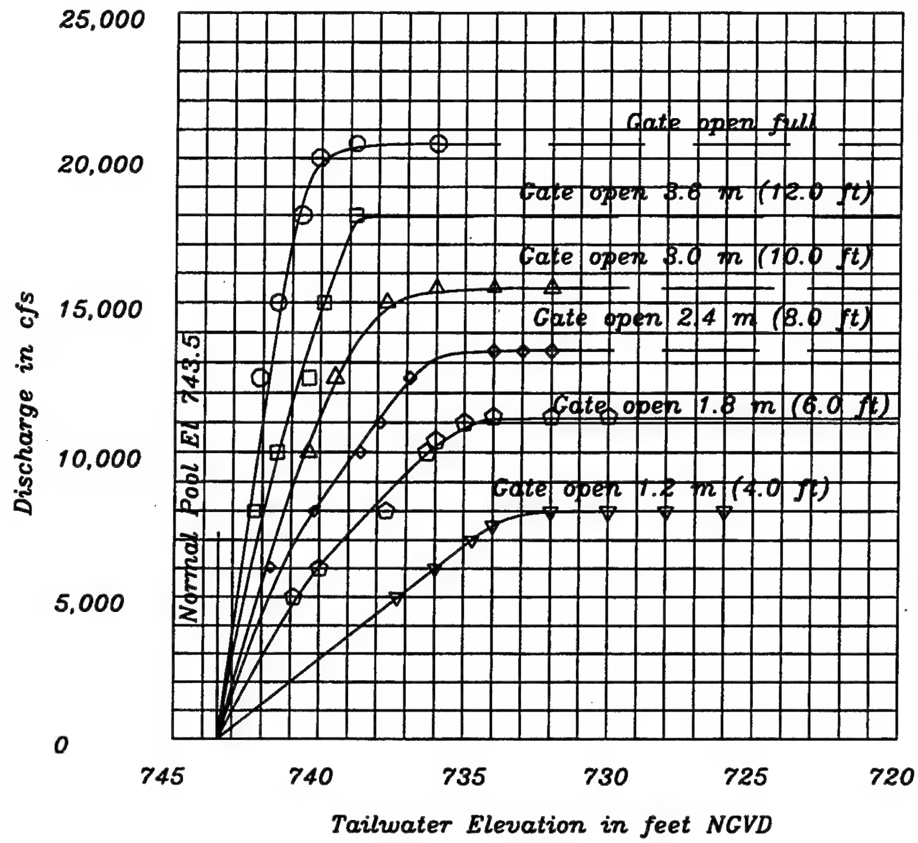
CALIBRATION DATA
FOR CONTROLLED FLOW
CRESTELEVATION 724.0
GATE OPENING 1.8 M (6.0 FT)



CALIBRATION DATA
FOR CONTROLLED FLOW
CREST ELEVATION 724.0
GATE OPENING 2.4 M (8.0 FT)

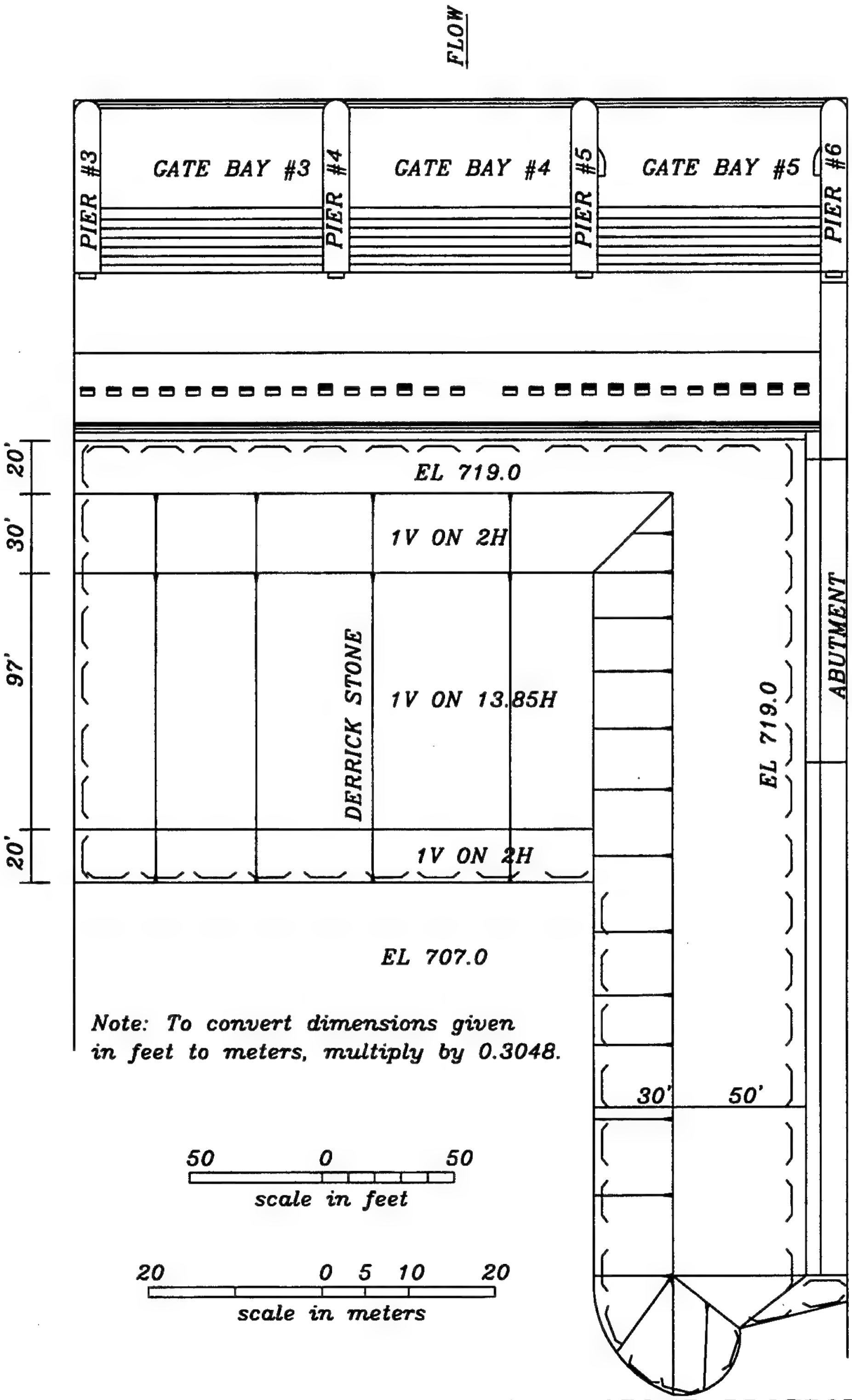


CALIBRATION DATA
FOR CONTROLLED FLOW
CREST ELEVATION 724.0
GATE OPENING 3.0 M (10.0 FT)

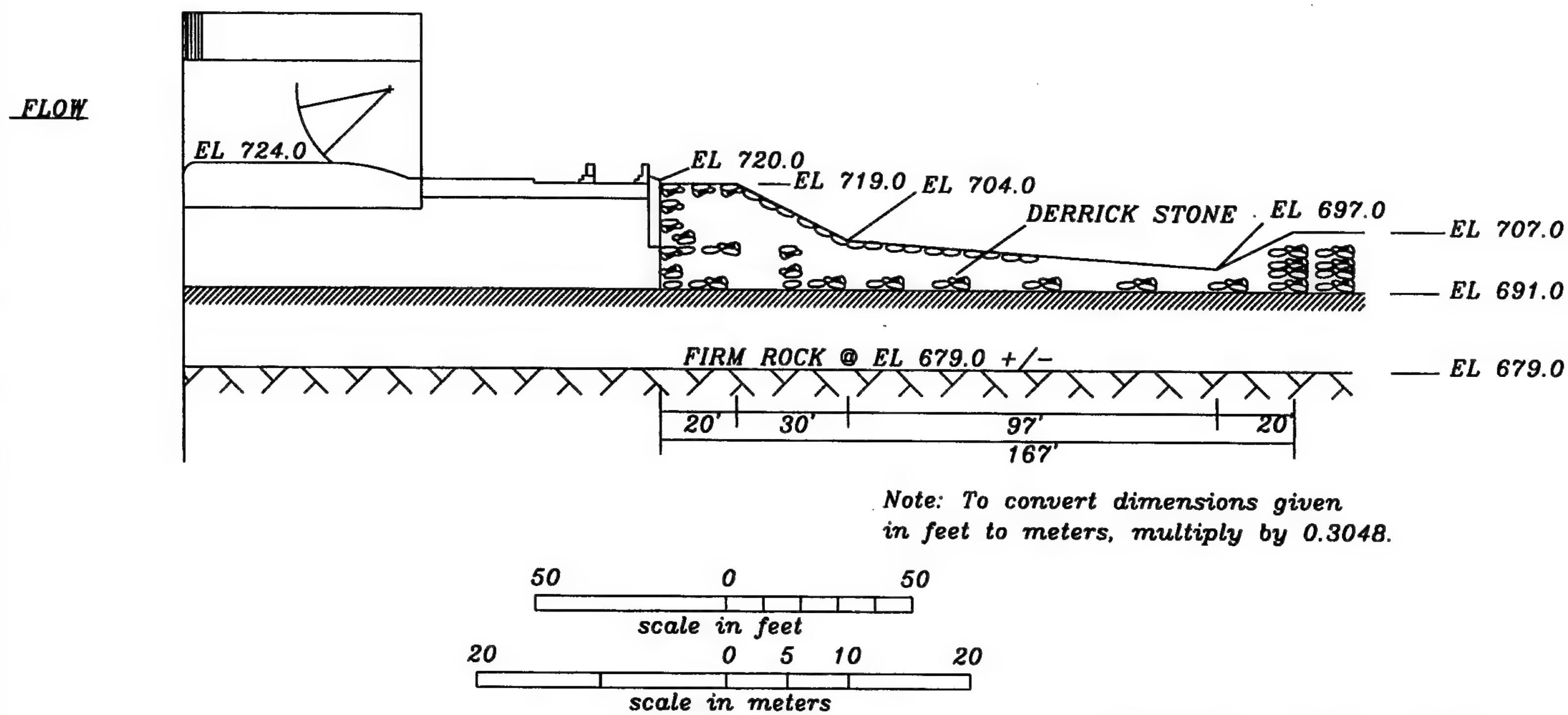


Note: To convert discharge to cubic meters per second, multiply by 0.028.

TAILWATER EFFECT
ON DISCHARGE
CREST ELEVATION 724.0
POOL ELEVATION 743.5

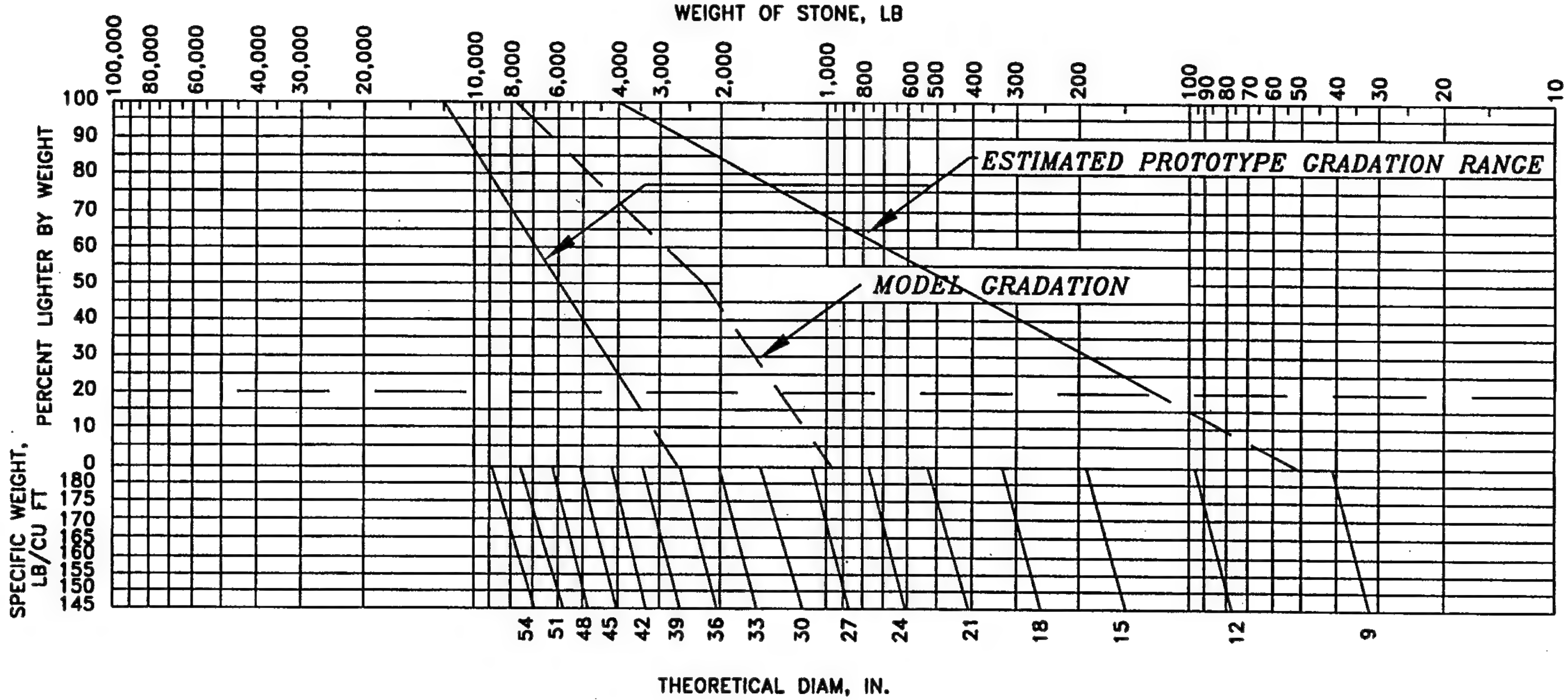


EXISTING STONE PROTECTION
CONFIGURATION 2
PLAN VIEW



EXISTING STONE PROTECTION
CONFIGURATION 2
PROFILE

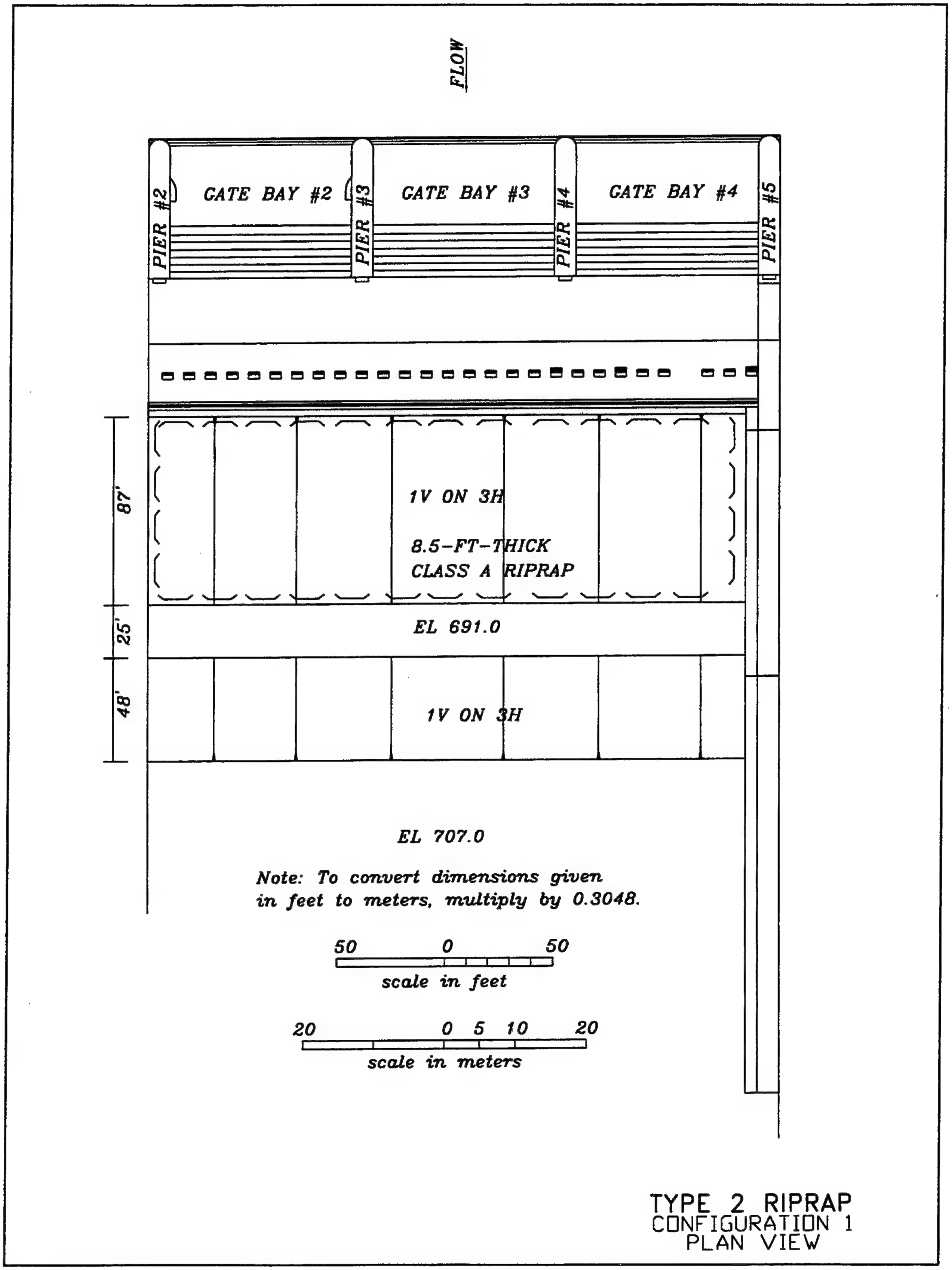
Plate 14



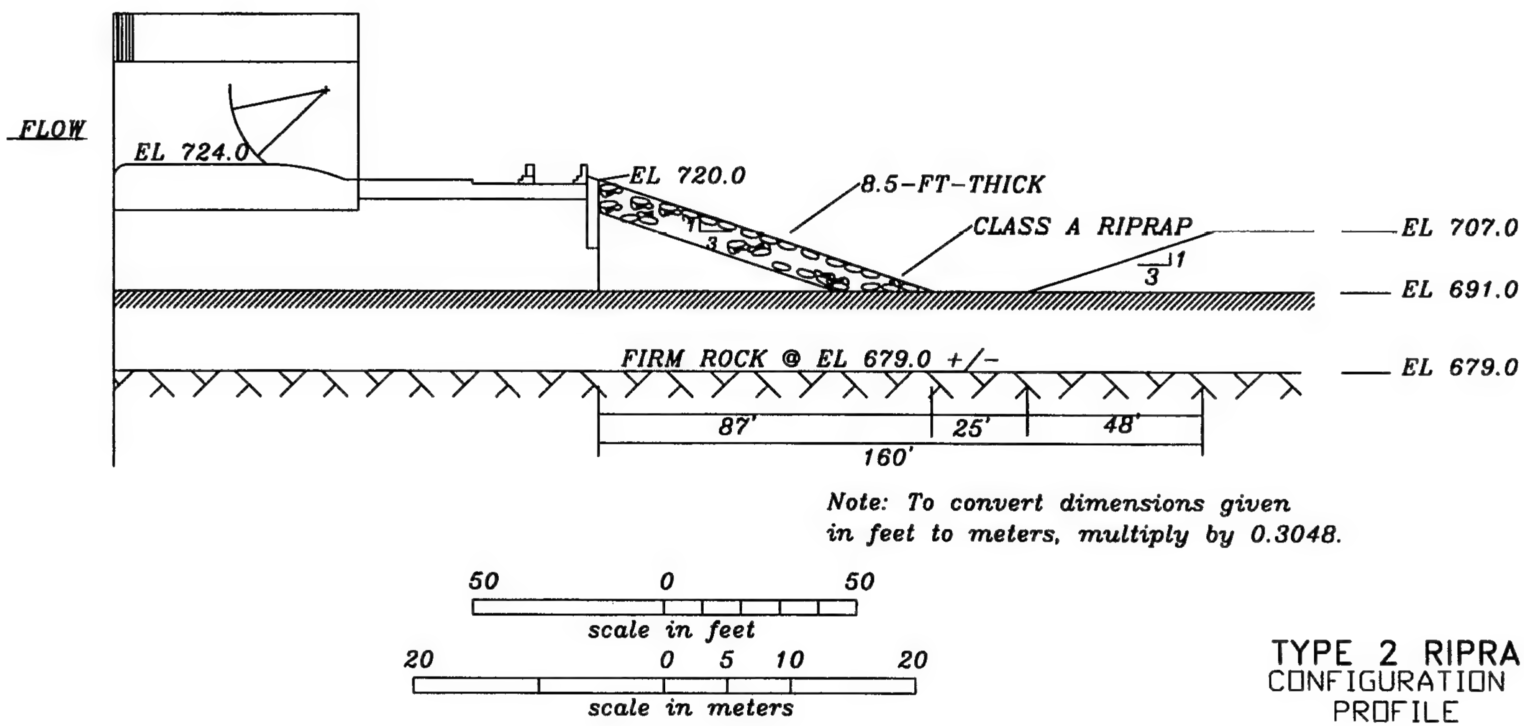
Note: To convert Non-SI units of measure used in this plate to SI units, multiply as shown:

Multiply	By	To Obtain
inches	25.4	millimeters
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter

DERRICK STONE

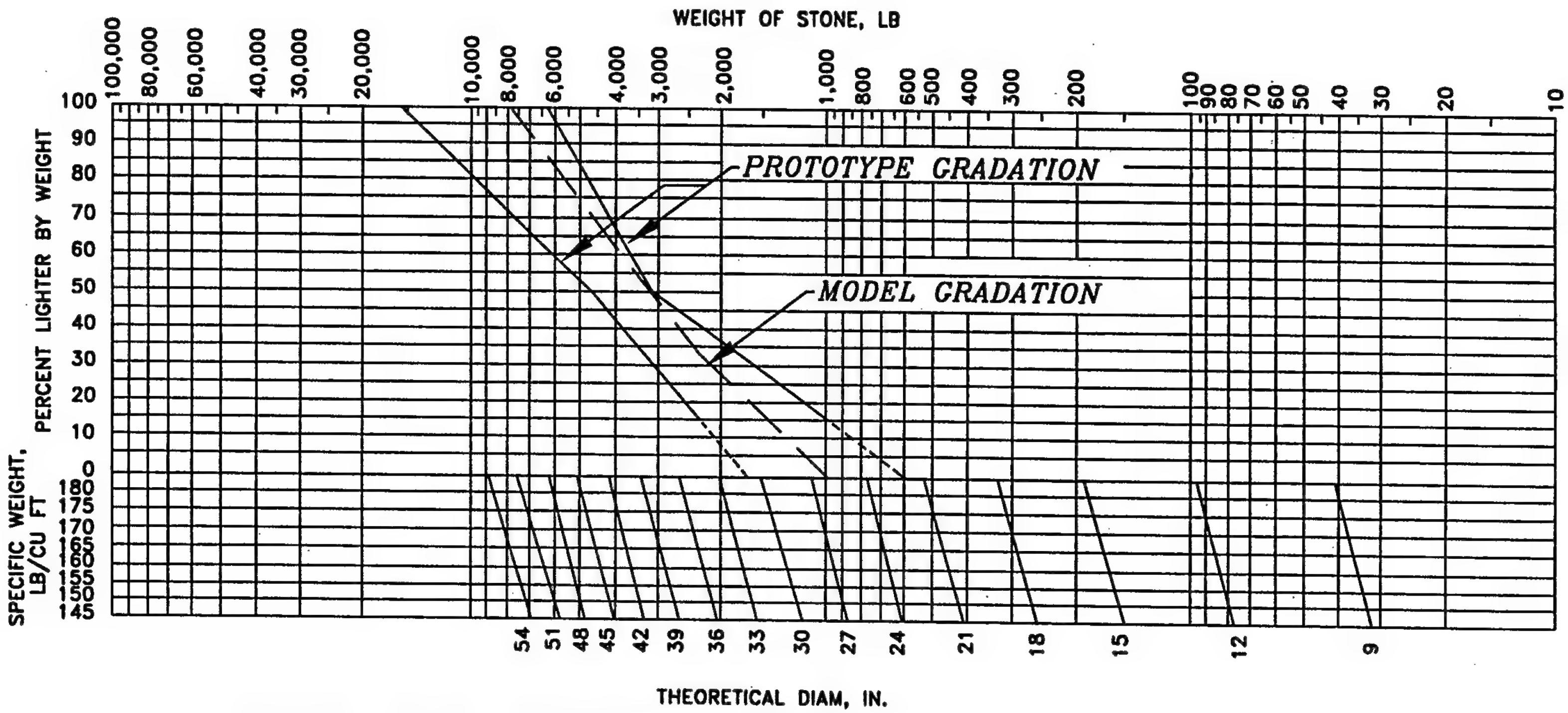


FLOW
GATE BAY #2
GATE BAY #3
GATE BAY #4
PIER #2
PIER #3
PIER #4
PIER #5
87'
25'
48'
1V ON 3H
8.5-FT-THICK
CLASS A RIPRAP
EL 691.0
1V ON 3H
EL 707.0
Note: To convert dimensions given
in feet to meters, multiply by 0.3048.
50 0 50
scale in feet
20 0 5 10 20
scale in meters
TYPE 2 RIPRAP
CONFIGURATION 1
PLAN VIEW



Note: To convert dimensions given in feet to meters, multiply by 0.3048.

TYPE 2 RIPRAP
CONFIGURATION 1
PROFILE

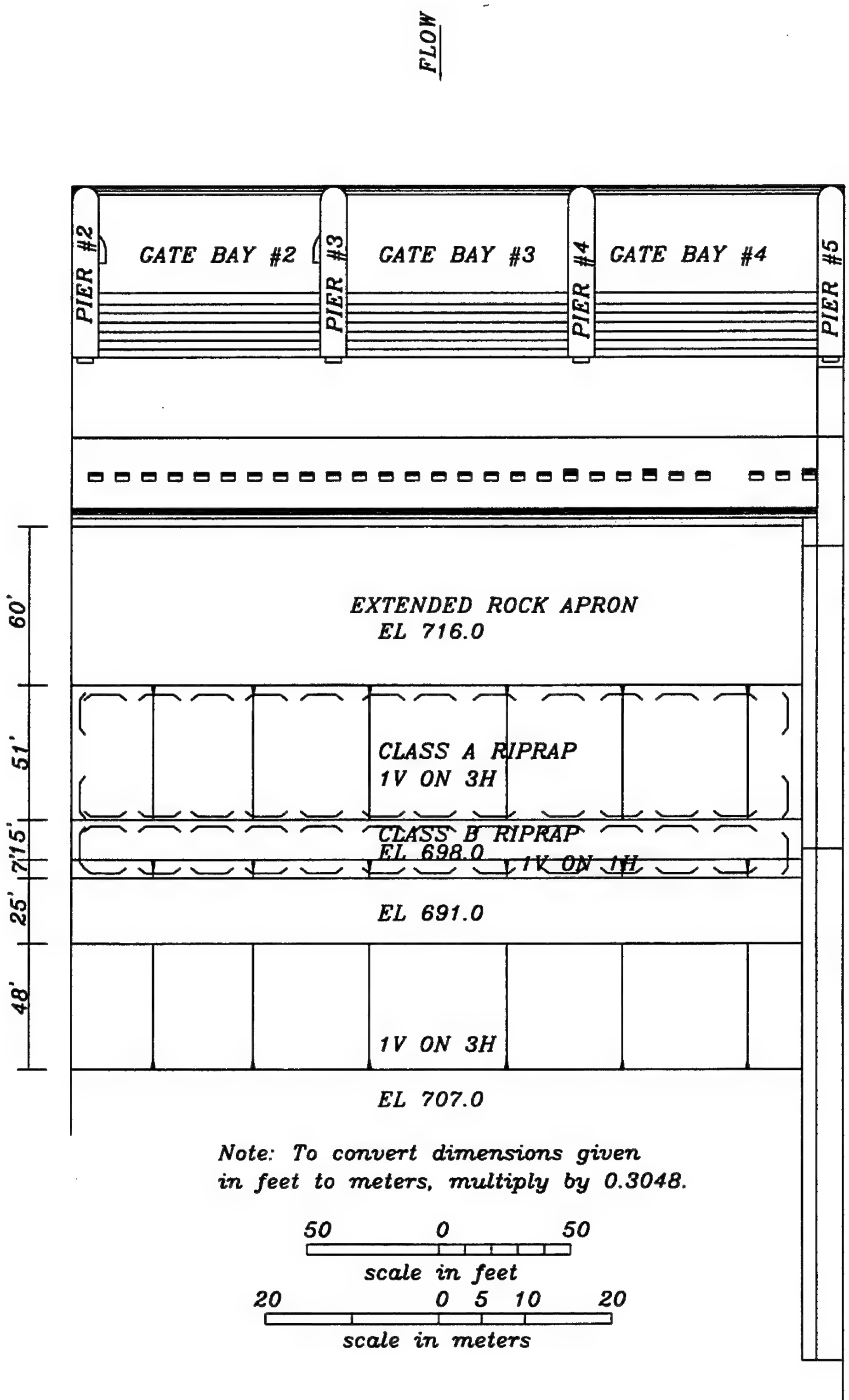


SPECIFIC WEIGHT OF STONE 165 LB/CU FT

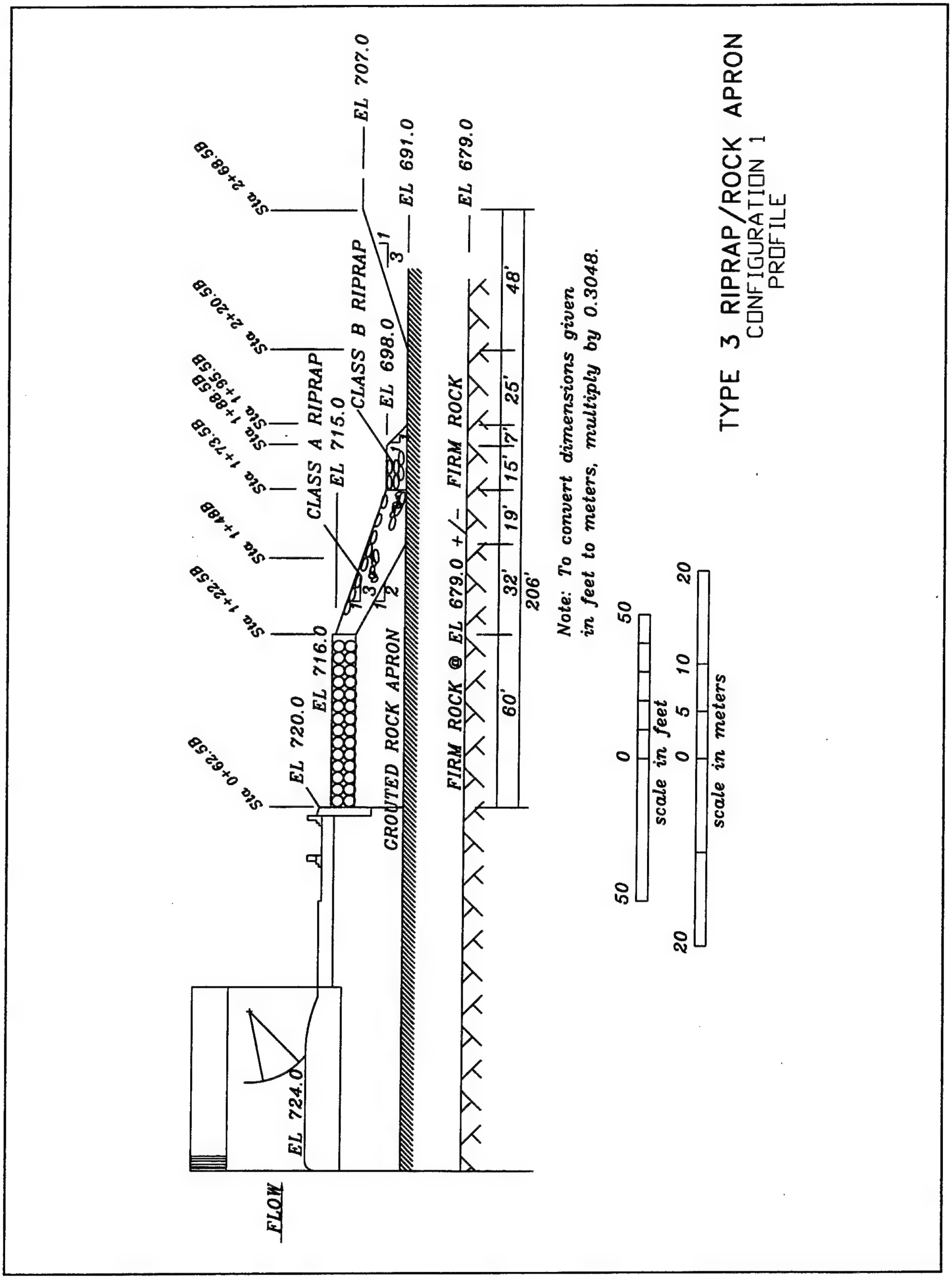
Note: *To convert Non-SI units of measure used in this plate to SI units, multiply as shown:*

Multiply	*By*	*To Obtain*
inches	*25.4*	*millimeters*
pounds (mass)	*0.4535924*	*kilograms*
pounds (mass) per cubic foot	*16.01846*	*kilograms per cubic meter*

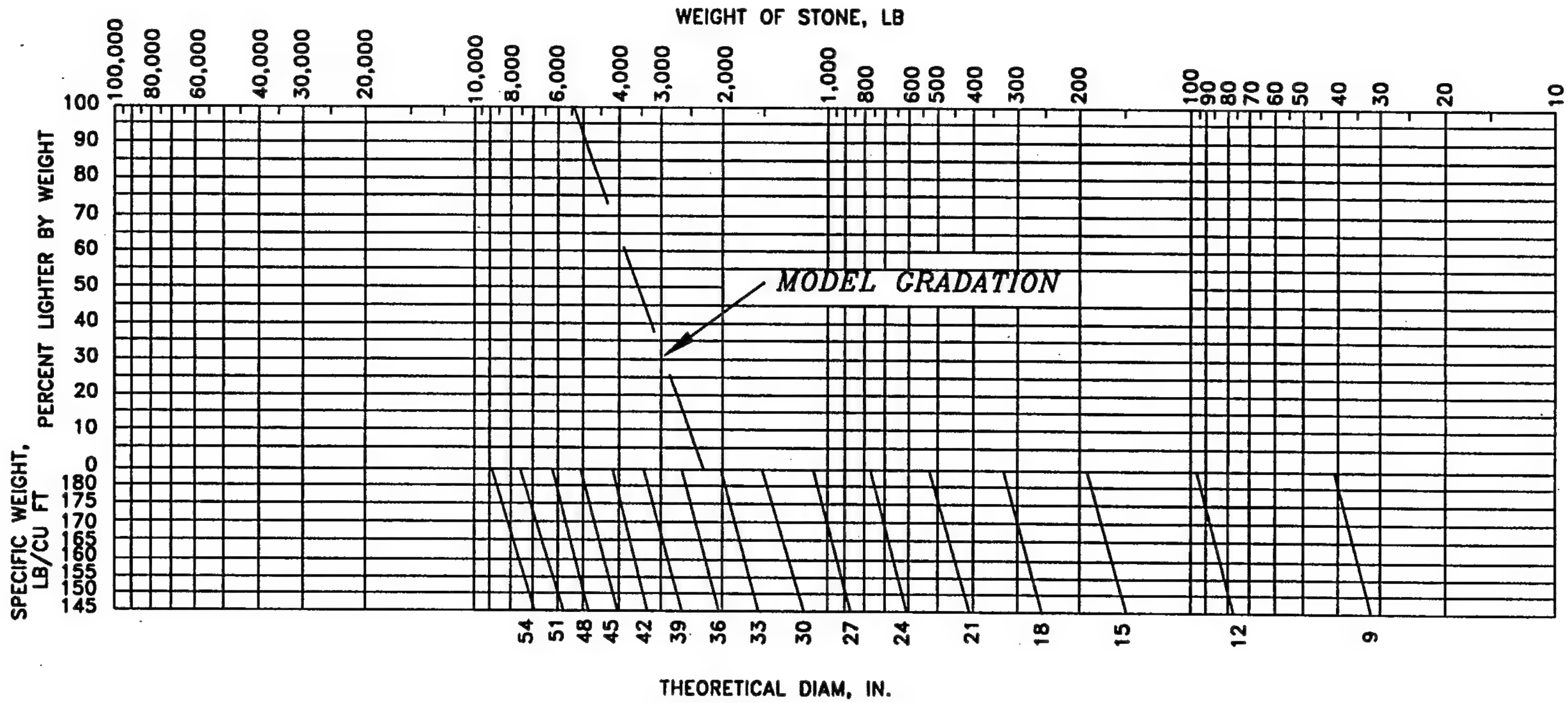
CLASS A RIPRAP
2.6 m (8.5 ft)



TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
PLAN VIEW



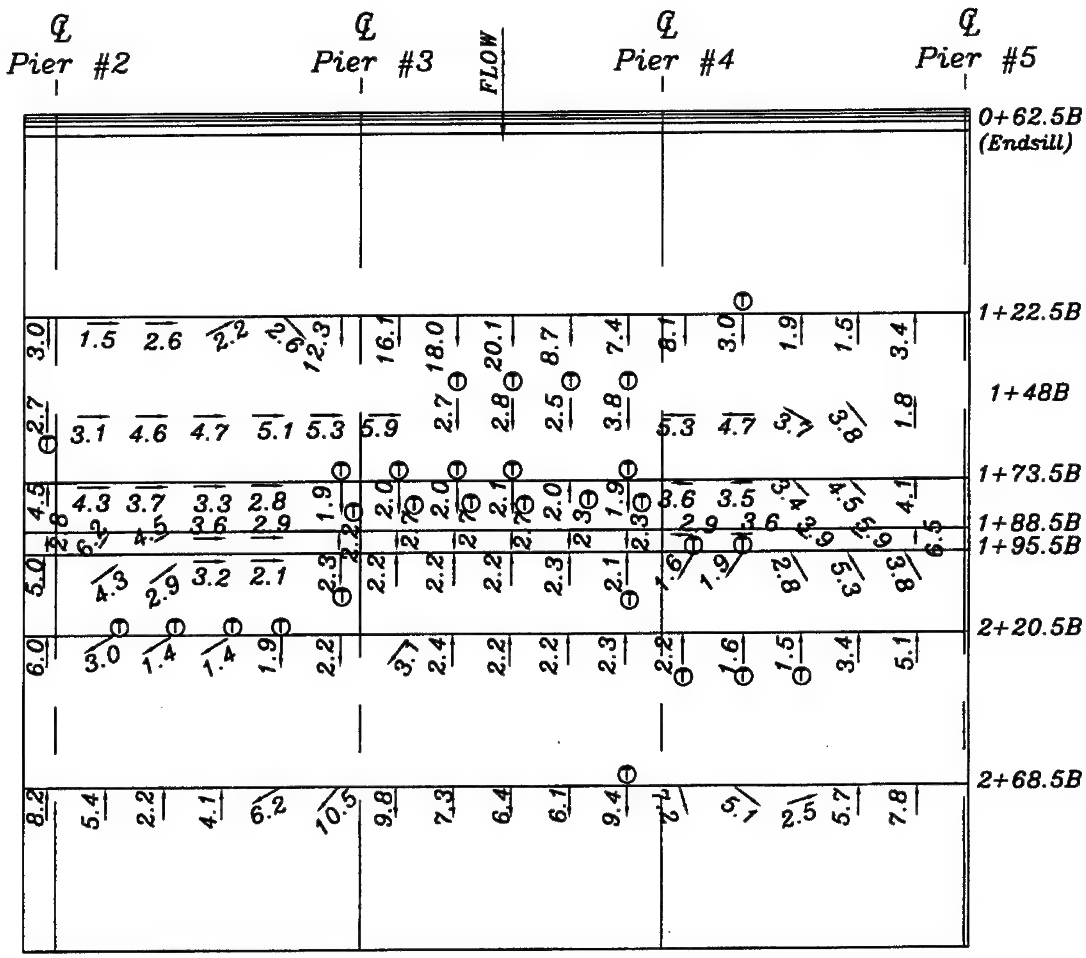
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
PROFILE
FLOW
EL 724.0
EL 720.0
EL 716.0
EL 715.0
EL 698.0
EL 707.0
EL 691.0
EL 679.0
Sta 0+62.5B
Sta 1+22.5B
Sta 1+48B
Sta 1+73.5B
Sta 1+88.5B
Sta 1+95.5B
Sta 2+20.5B
Sta 2+68.5B
CLASS A RIPRAP
CLASS B RIPRAP
GROUTED ROCK APRON
FIRM ROCK @ EL 679.0 +/- FIRM ROCK
60'
32'
19'
15'
7'
25'
48'
206'
Note: To convert dimensions given in feet to meters, multiply by 0.3048.
scale in feet
50 0 5 10 50
scale in meters
20 0 5 10 20



Note: To convert Non-SI units of measure used in this plate to SI units, multiply as shown:

Multiply	*By*	*To Obtain*
inches	*25.4*	*millimeters*
pounds (mass)	*0.4535924*	*kilograms*
pounds (mass) per cubic foot	*16.01846*	*kilograms per cubic meter*

CLASS B RIPRAP



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

Ⓣ = Turbulence

BOTTOM VELOCITIES

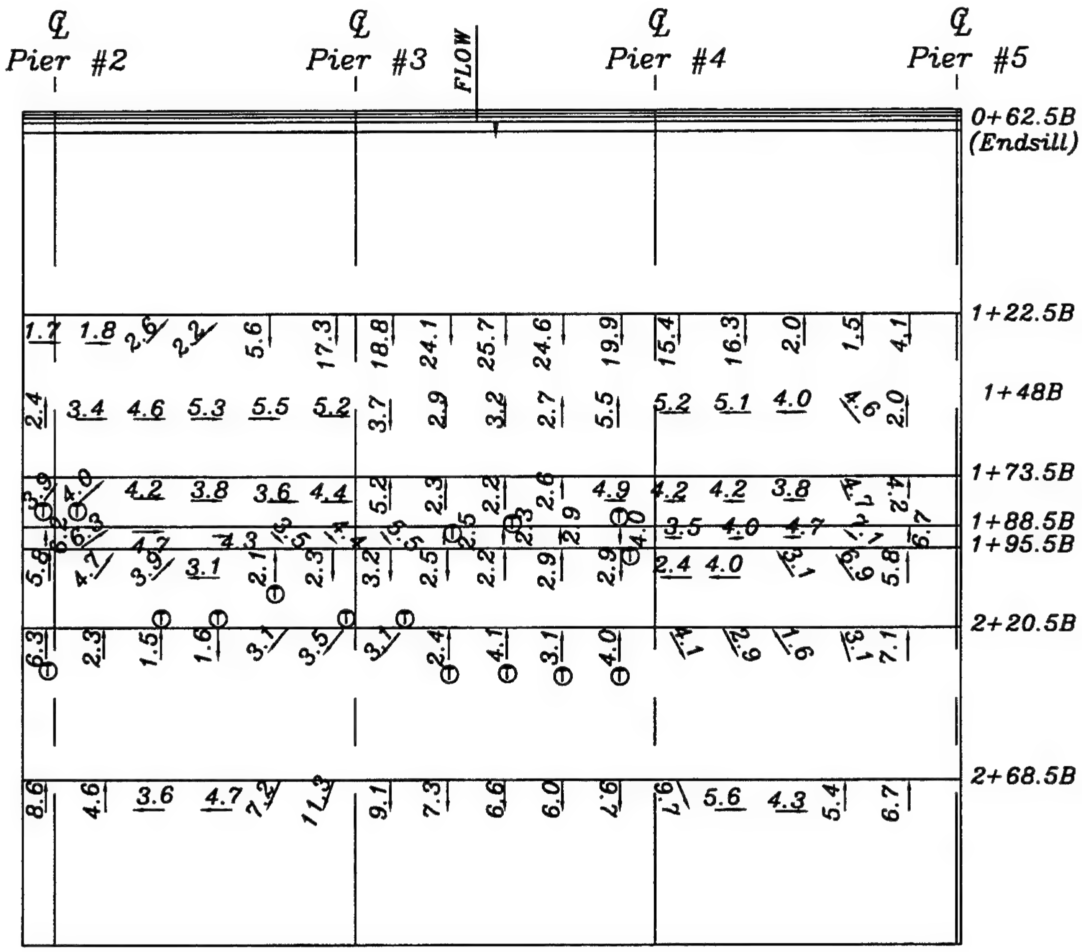
TYPE 3 RIPRAP/ROCK APRON

CONFIGURATION 1

Q = 314 CU M/SEC (11,200 CFS)

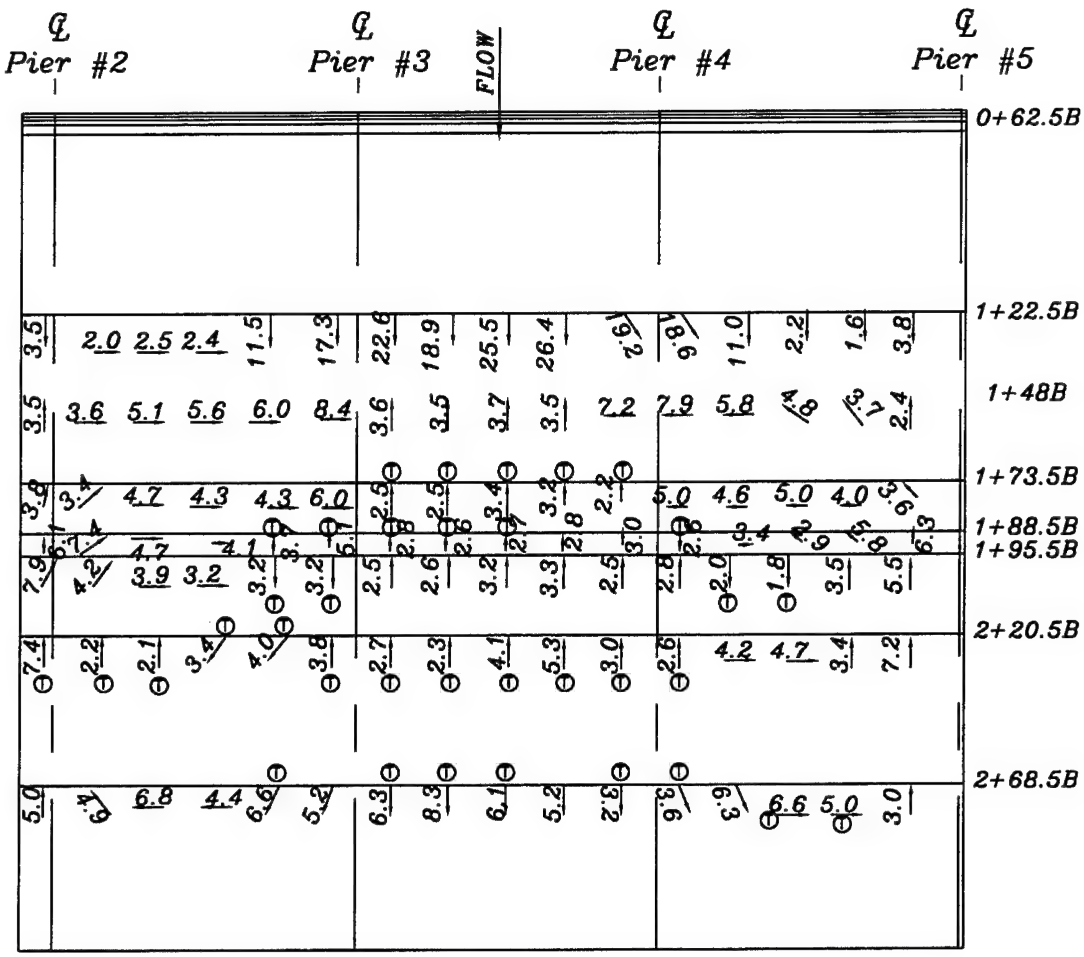
G_2 = 0 ft, G_3 = 1.8 m (6 ft), G_4 = 0 ft

POOL EL 743.5, TW EL 723.7



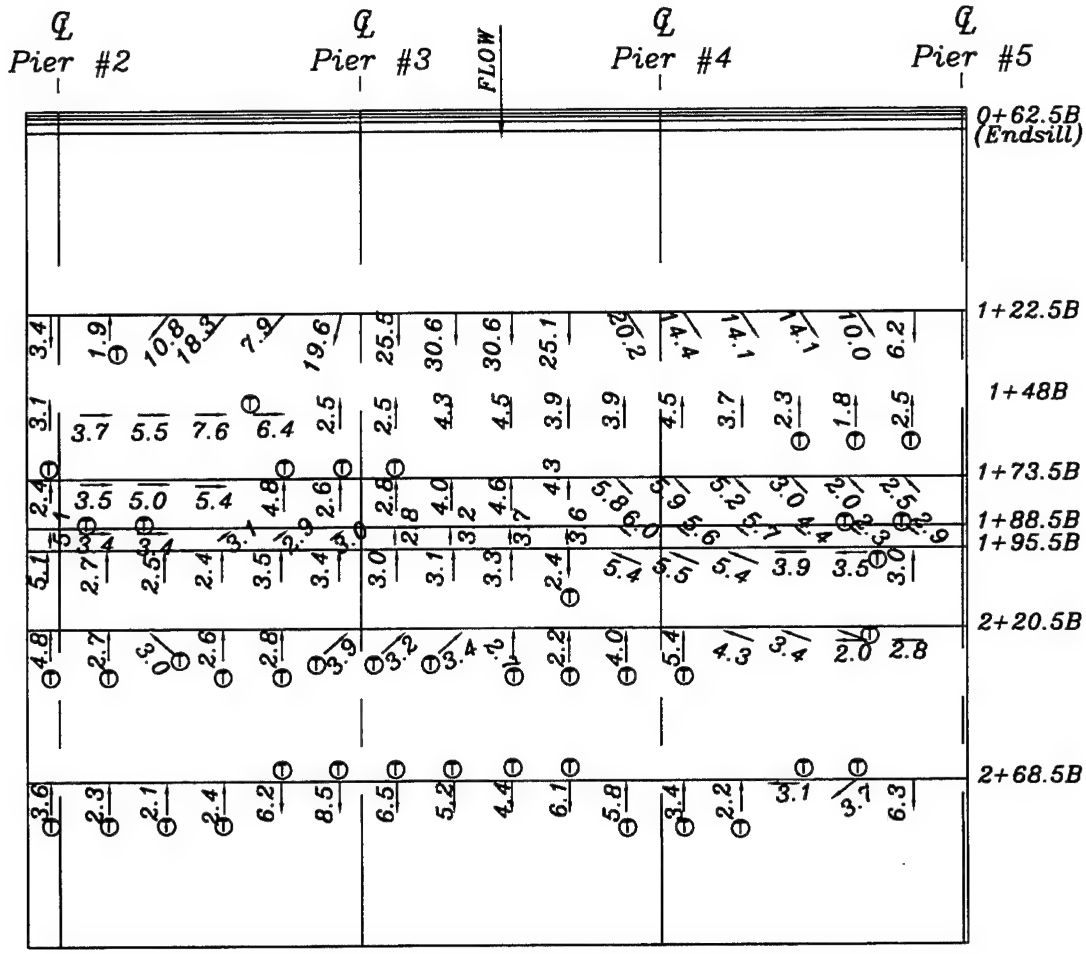
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 378 CU M/SEC (13,500 CFS)
G_2 = 0 ft, G_3 = 2.4 m (8 ft), G_4 = 0 ft
POOL EL 743.5, TW EL 723.7



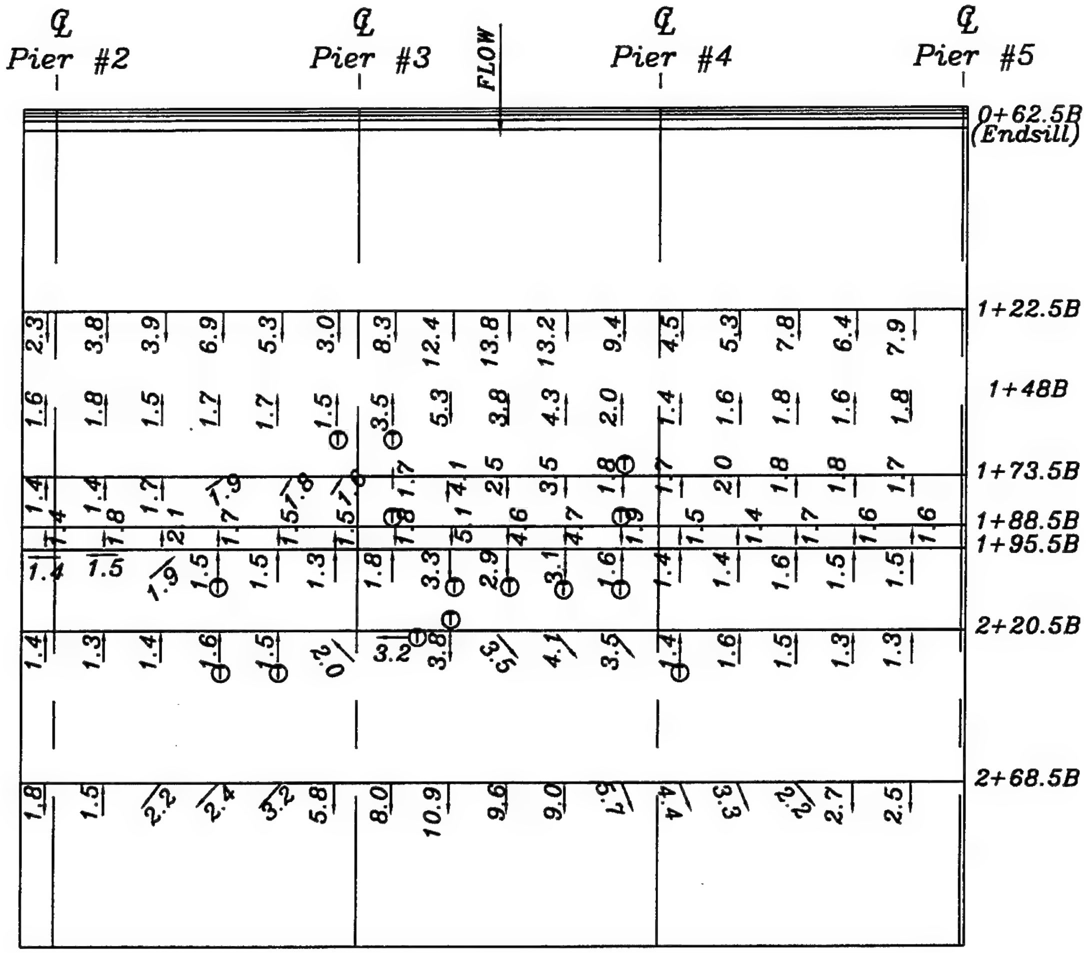
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 437 CU M/SEC (15,600 CFS)
G_2 = 0 ft, G_3 = 3.0 m (10 ft), G_4 = 0 ft
POOL EL 743.5, TW EL 723.7



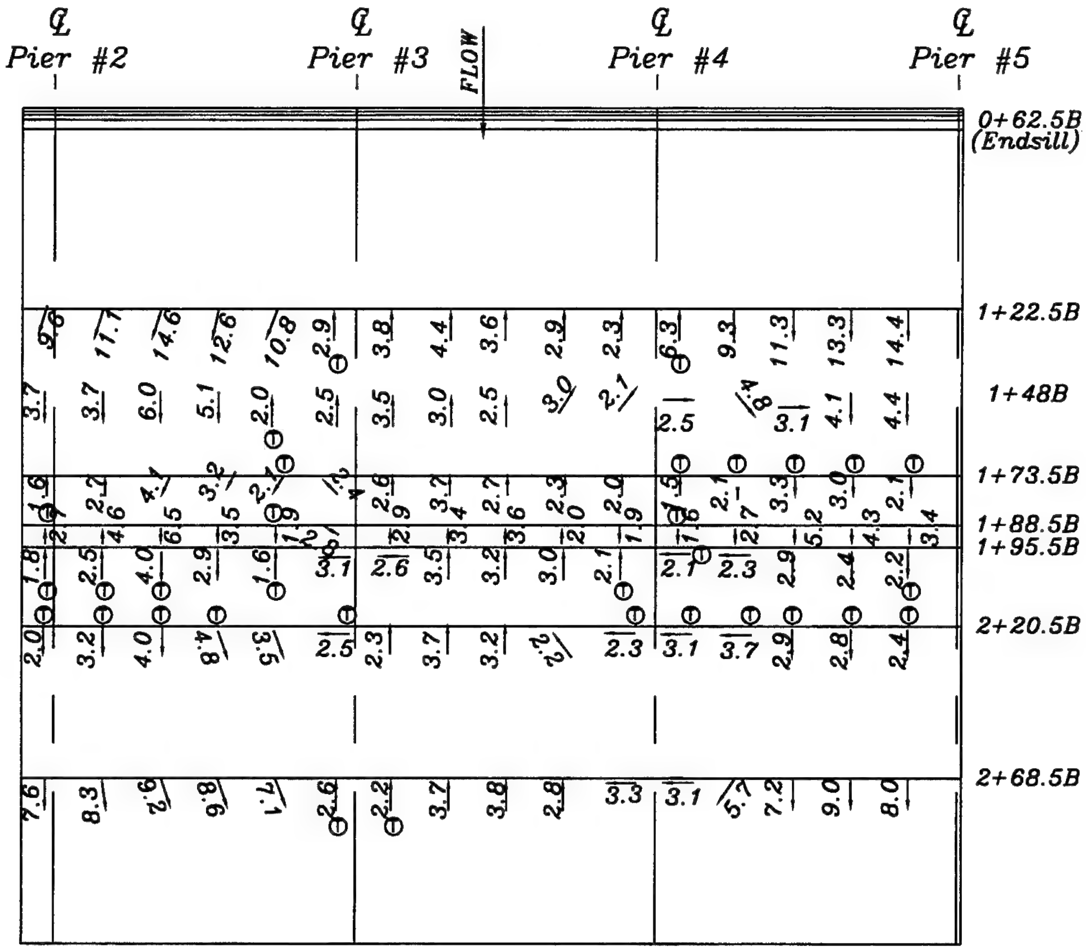
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 574 CU M/SEC (20,500 CFS)
G_2 = 0 ft, G_3 = FULL, G_4 = 0 ft
POOL EL 743.5, TW EL 723.7



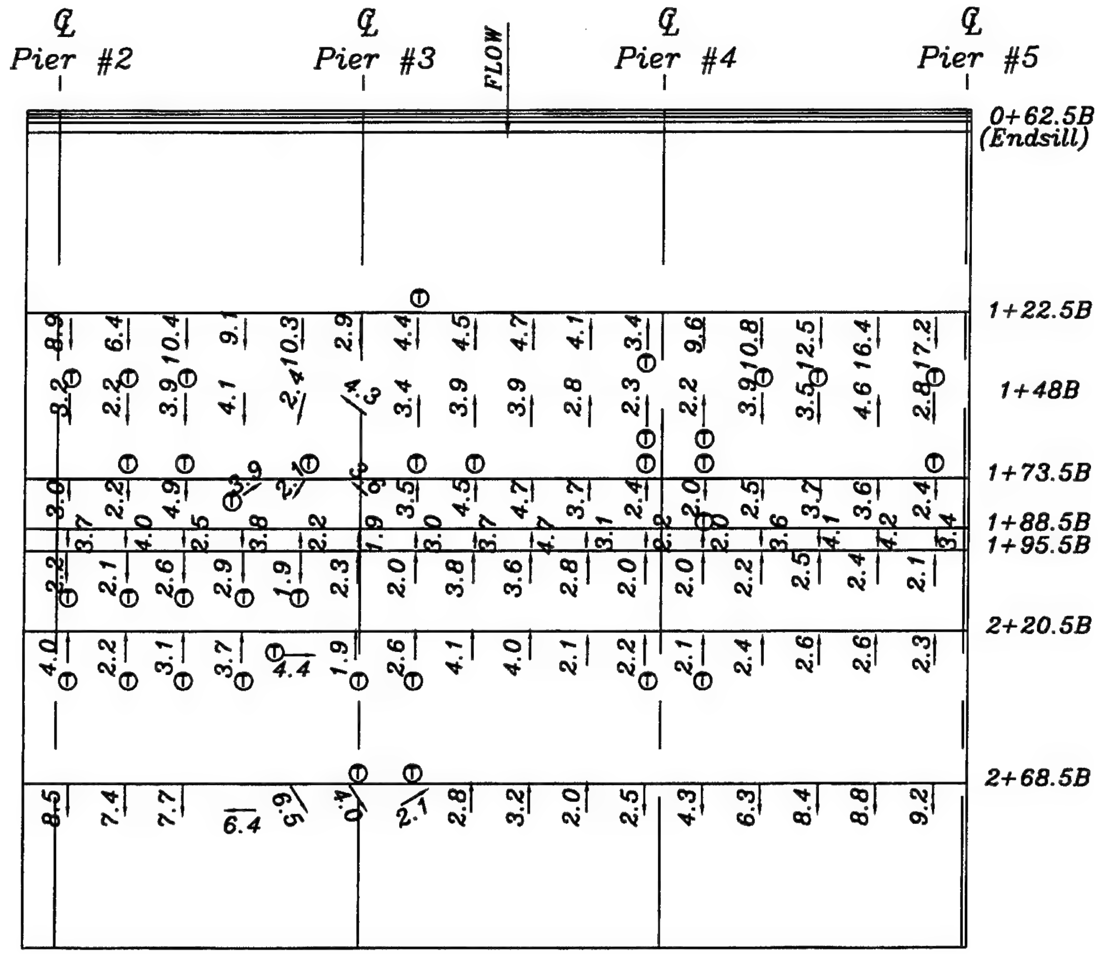
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
⊕ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 762 CU M/SEC (27,200 CFS)
G_2 = 1.2 m (4 ft), G_3 = 1.8 m (6 ft),
G_4 = 1.2 m (4 ft)
POOL EL 743.5, TW EL 730.6



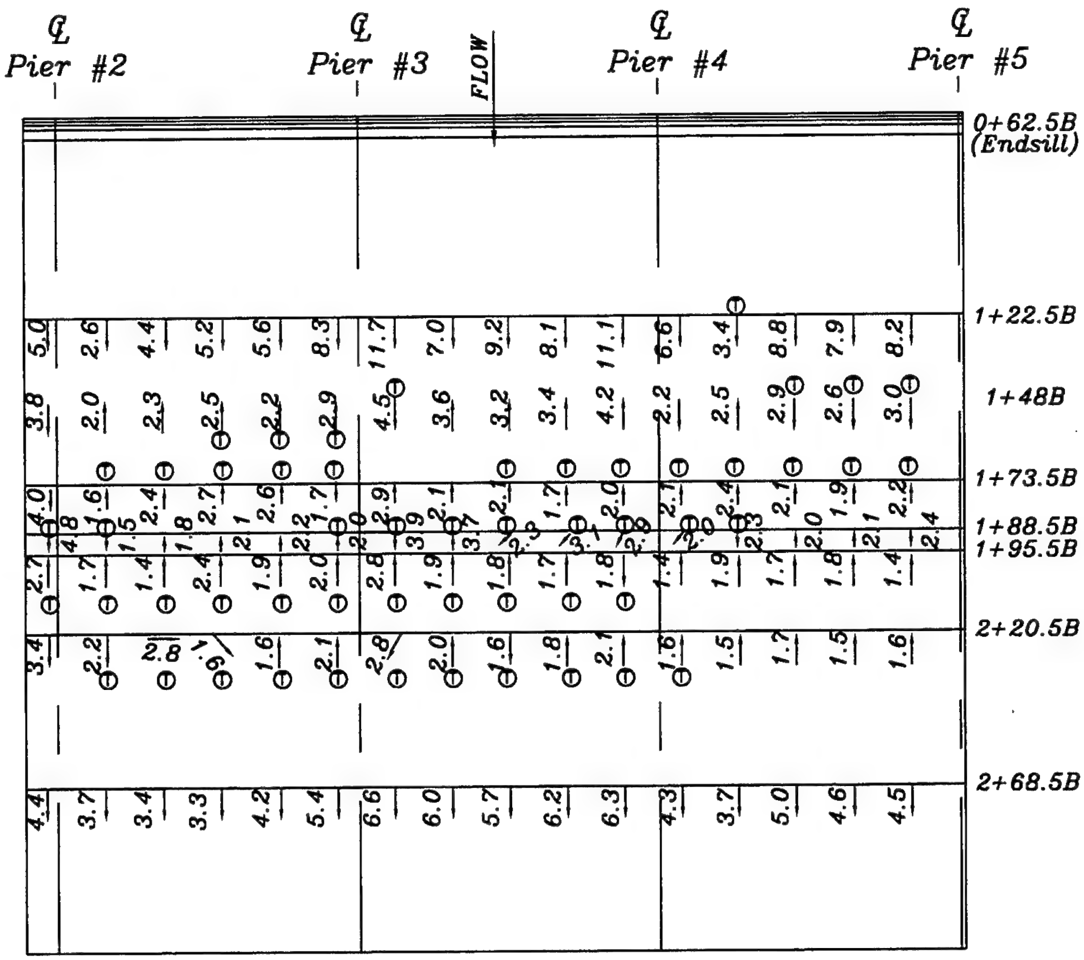
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 815 CU M/SEC (29,100 CFS)
G_2 = 3.0 m (10 ft), G_3 = 0 ft,
G_4 = 2.4 m (8 ft)
POOL EL 743.5, TW EL 733.1



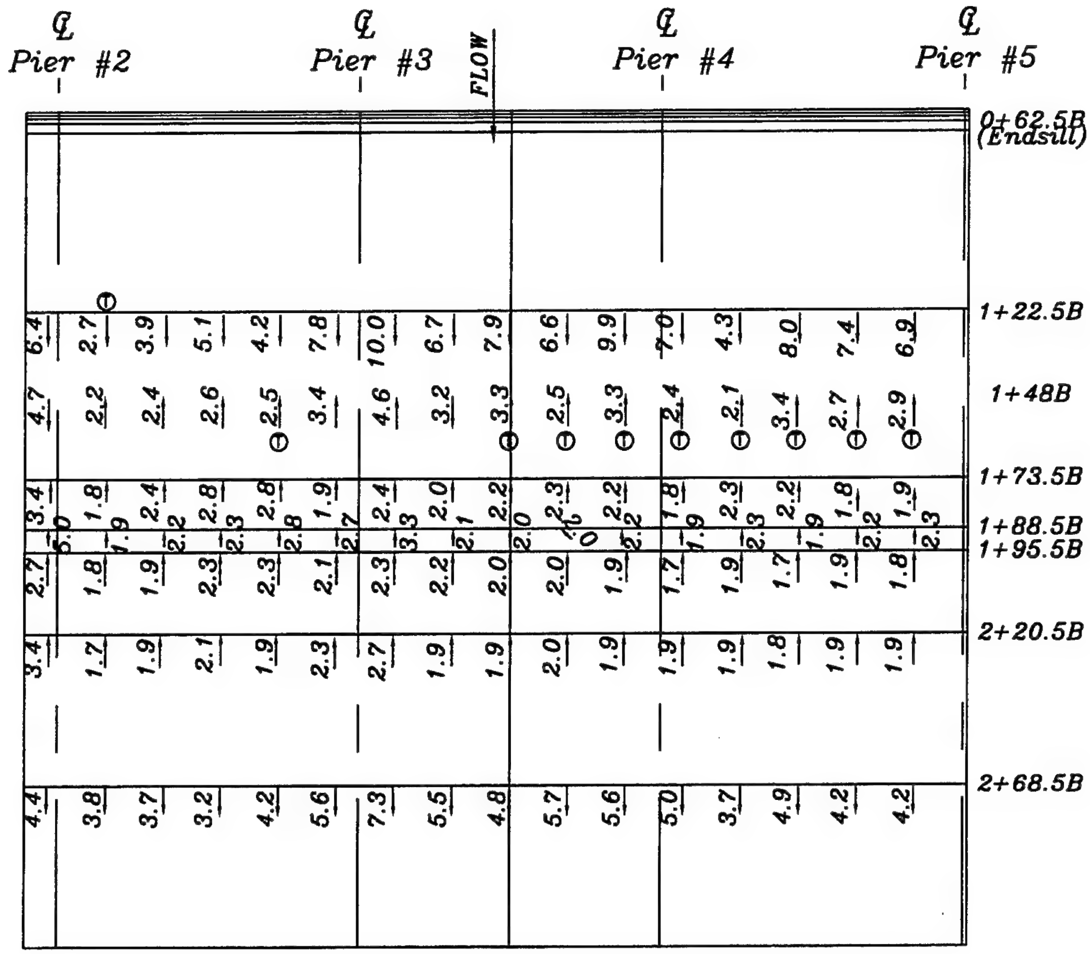
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 1,078 CU M/SEC (38,500 CFS)
G_2 = 3.6 m (12ft), G_3 = 0 ft, G_4 = FULL
POOL EL 743.5, TW EL 736.3



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 1,193 CU M/SEC (42,600 CFS)
G_2 = 2.4 m (8 ft), G_3 = 3.0 m (10 ft),
G_4 = 2.4 m (8 ft)
POOL EL 743.5, TW EL 735.5



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

Ⓣ = Turbulence

BOTTOM VELOCITIES

TYPE 3 RIPRAP/ROCK APRON

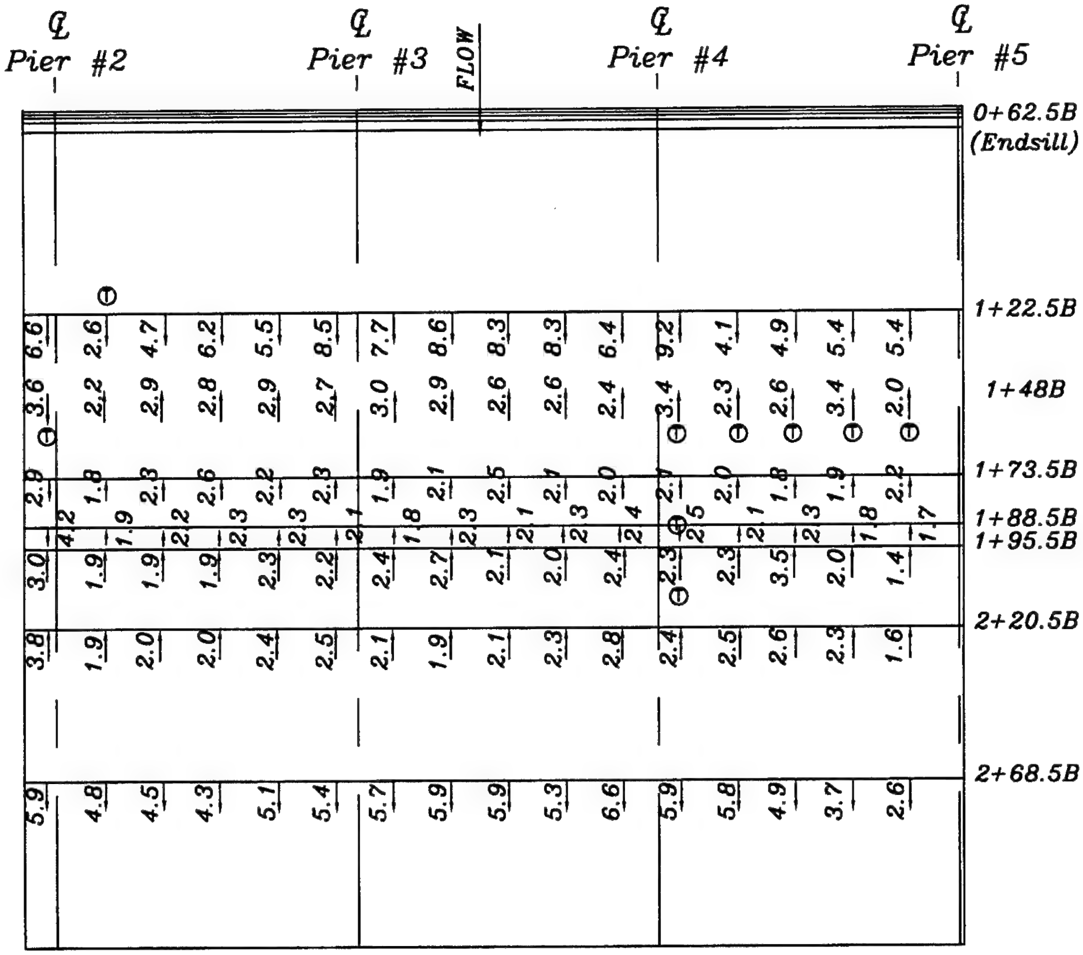
CONFIGURATION 1

Q = 1,366 CU M/SEC (48,800 CFS)

G_2 = 3.0 m (10 ft), G_3 = 3.6 m (12 ft),

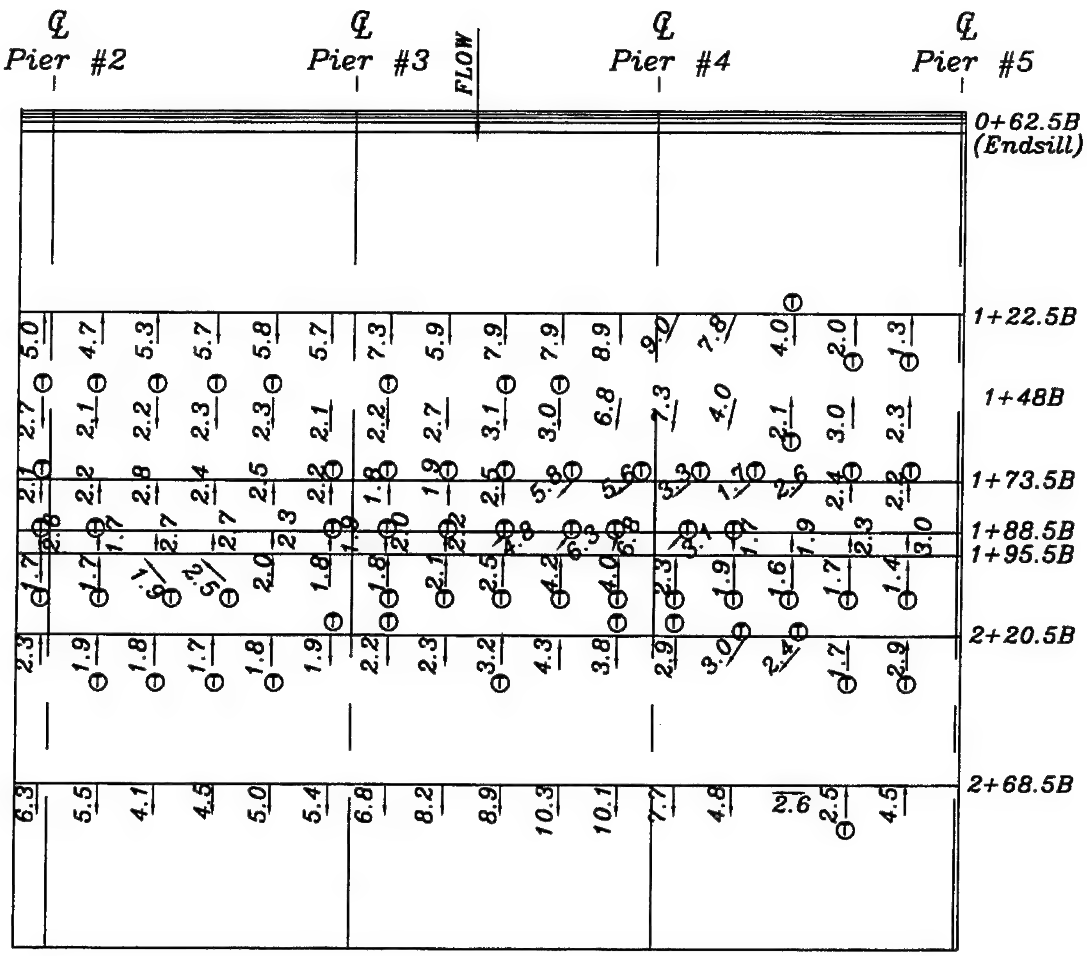
G_4 = 3.0 m (10 ft)

POOL EL 743.5, TW EL 737.1



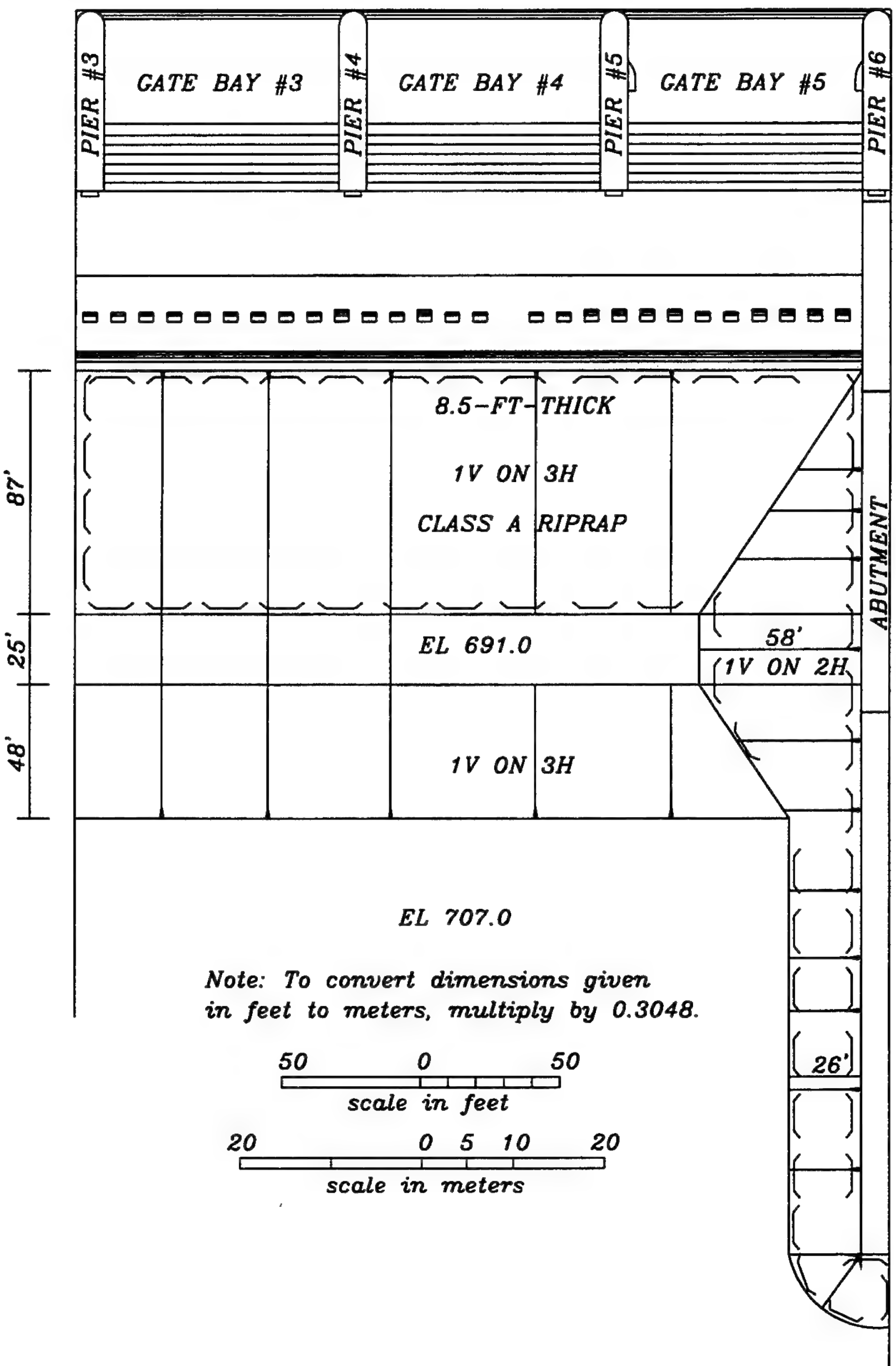
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 1,537 CU M/SEC (54,900 CFS)
G_2 = 3.6 m (12 ft), G_3 = FULL,
G_4 = 3.6 m (12 ft)
POOL EL 743.5, TW EL 739.0

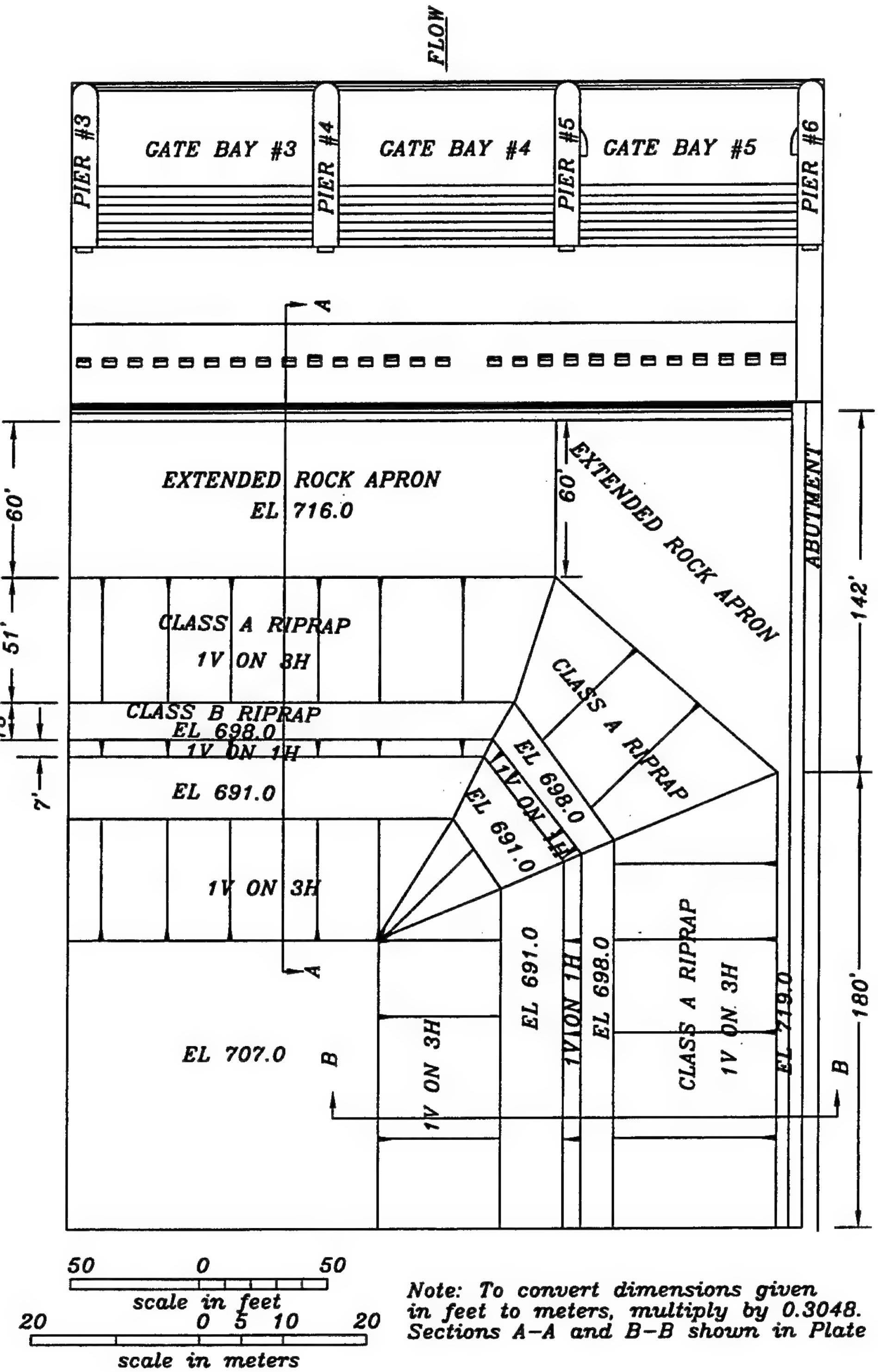


Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 1
Q = 1,630 CU M/SEC (58,200 CFS)
G_2 = FULL, G_3 = FULL, G_4 = FULL
POOL EL 743.5, TW EL 740.3

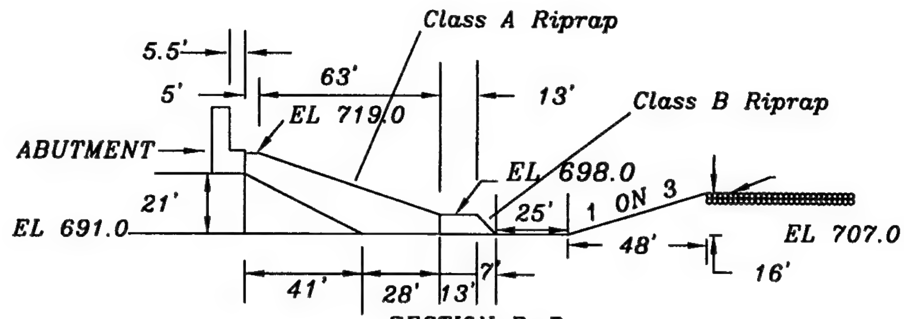


TYPE 2 RIPRAP
CONFIGURATION 2
PLAN VIEW

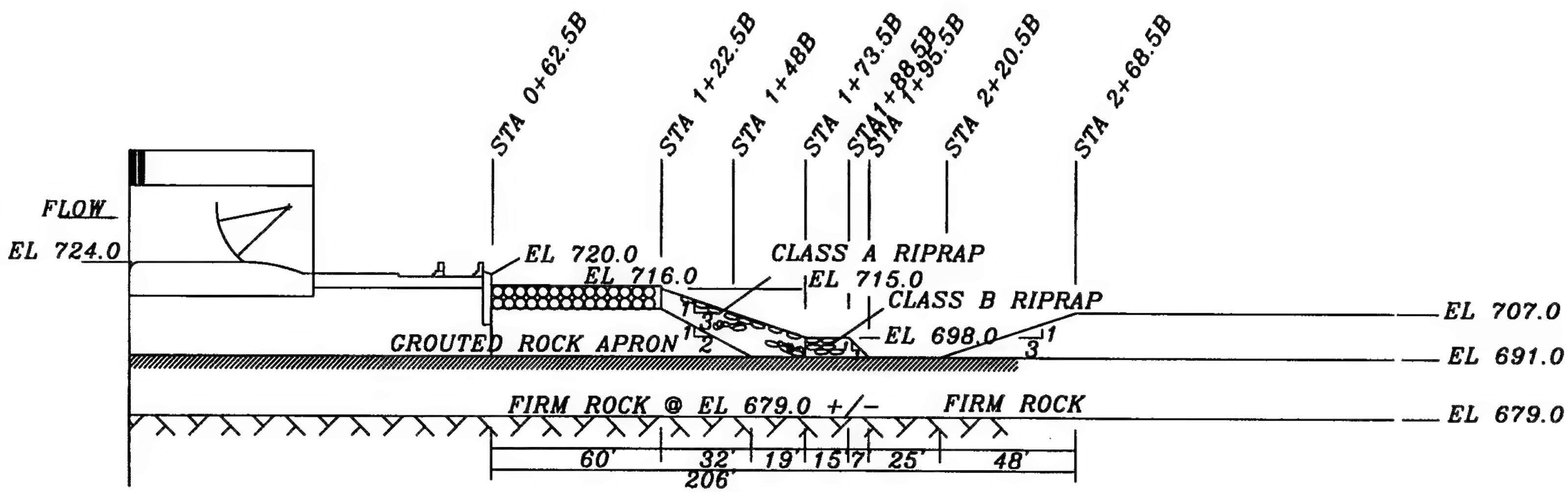


Note: To convert dimensions given in feet to meters, multiply by 0.3048. Sections A–A and B–B shown in Plate 35.

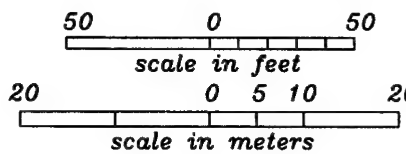
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
PLAN VIEW



SECTION B-B

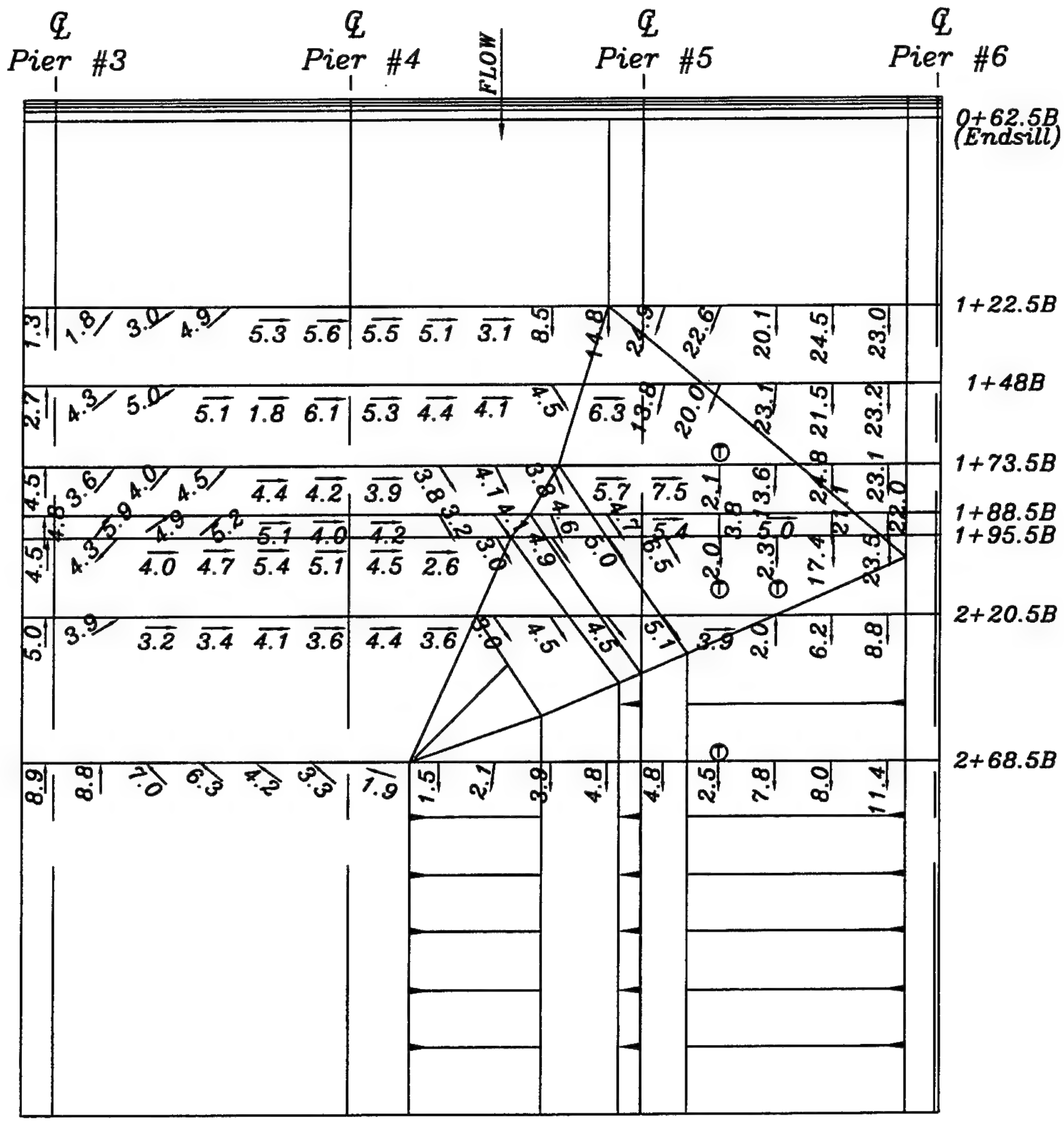


SECTION A-A



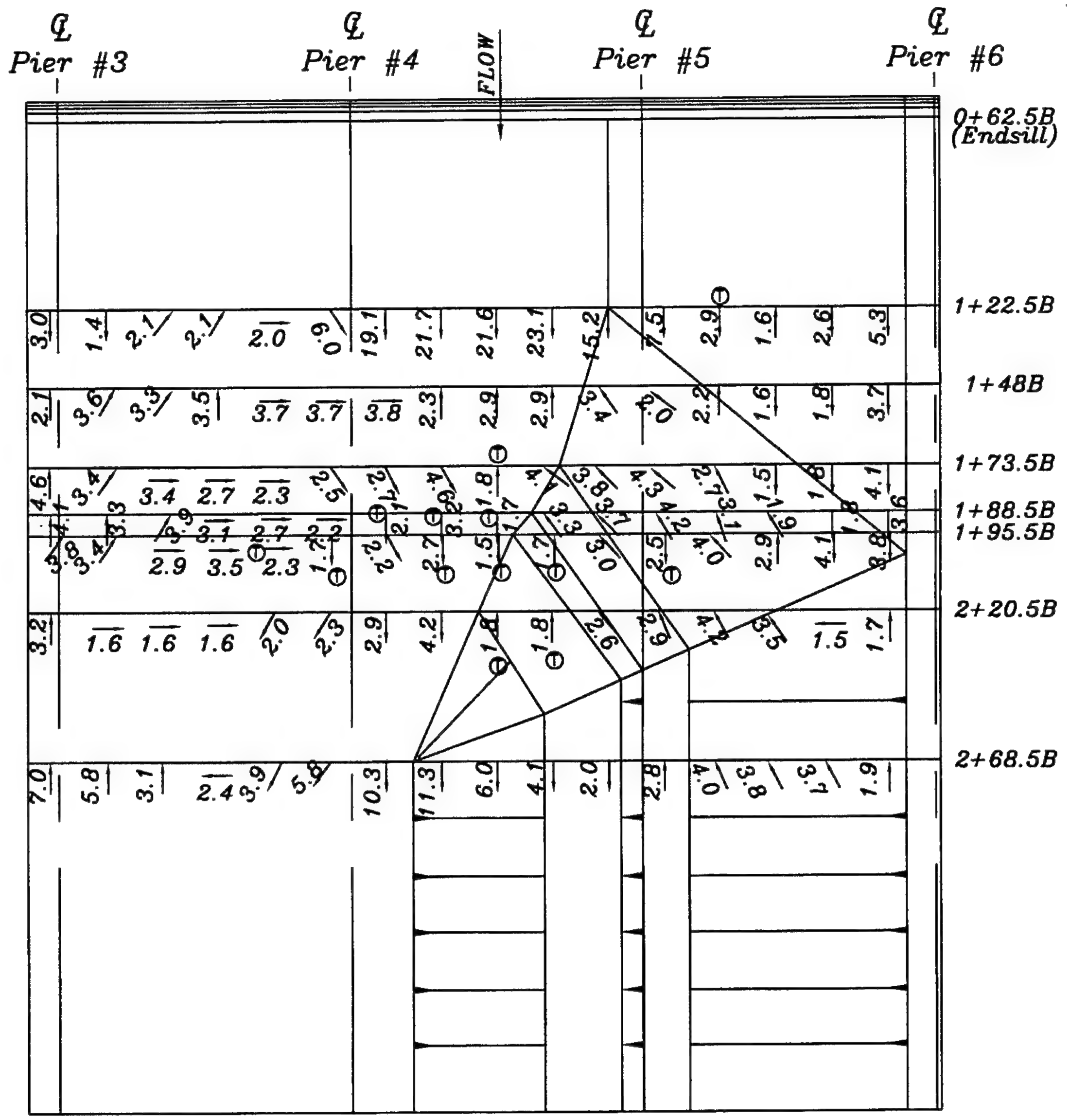
Note: To convert dimensions given in feet to meters, multiply by 0.3048.

TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
PROFILE AND END VIEWS



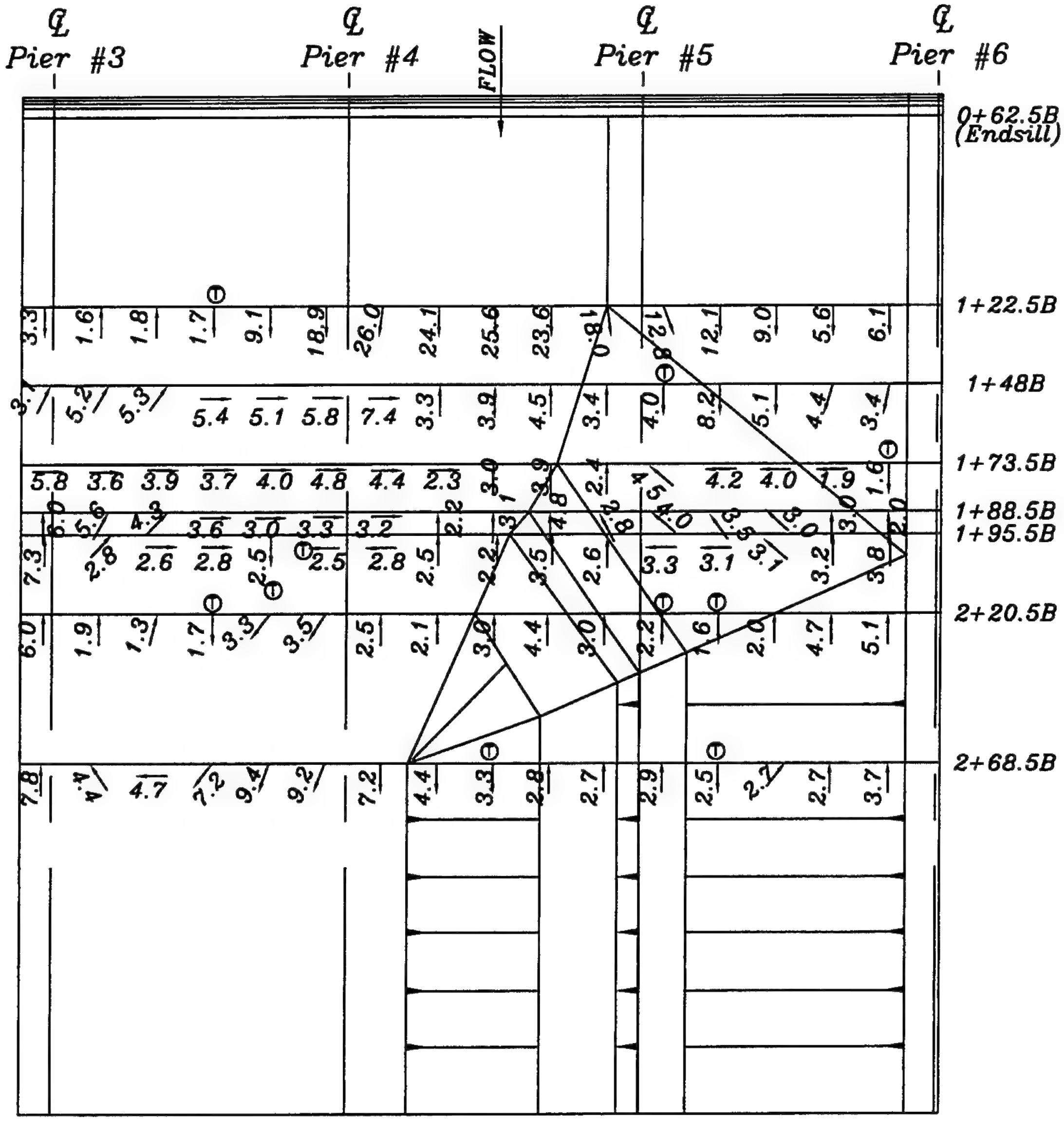
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
① = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 314 CU M/SEC (11,200 CFS)
G_3 = 0 ft, G_4 = 0 ft, G_5 = 1.8 m (6 ft)
POOL EL 743.5, TW EL 723.7



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 314 CU M/SEC (11,200 CFS)
G_3 = 0 ft, G_4 = 1.8 m (6 ft), G_5 = 0 ft
POOL EL 743.5, TW EL 723.7



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

Ⓣ = Turbulence

BOTTOM VELOCITIES

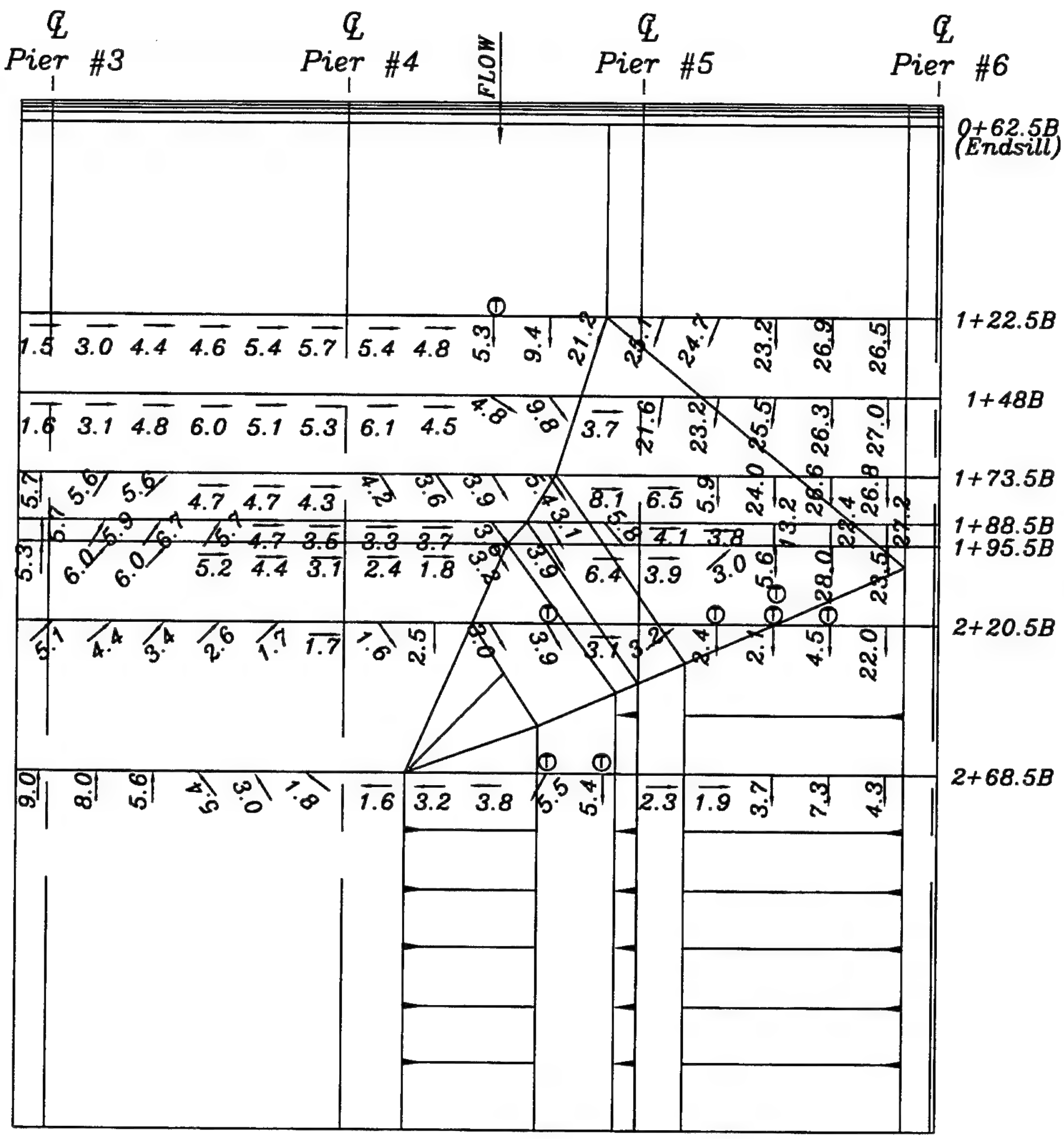
TYPE 3 RIPRAP/ROCK APRON

CONFIGURATION 2

Q = 378 CU M/SEC (13,500 CFS)

G_3 = 0 ft, G_4 = 2.4 m (8 ft), G_5 = 0 ft

POOL EL 743.5, TW EL 723.7

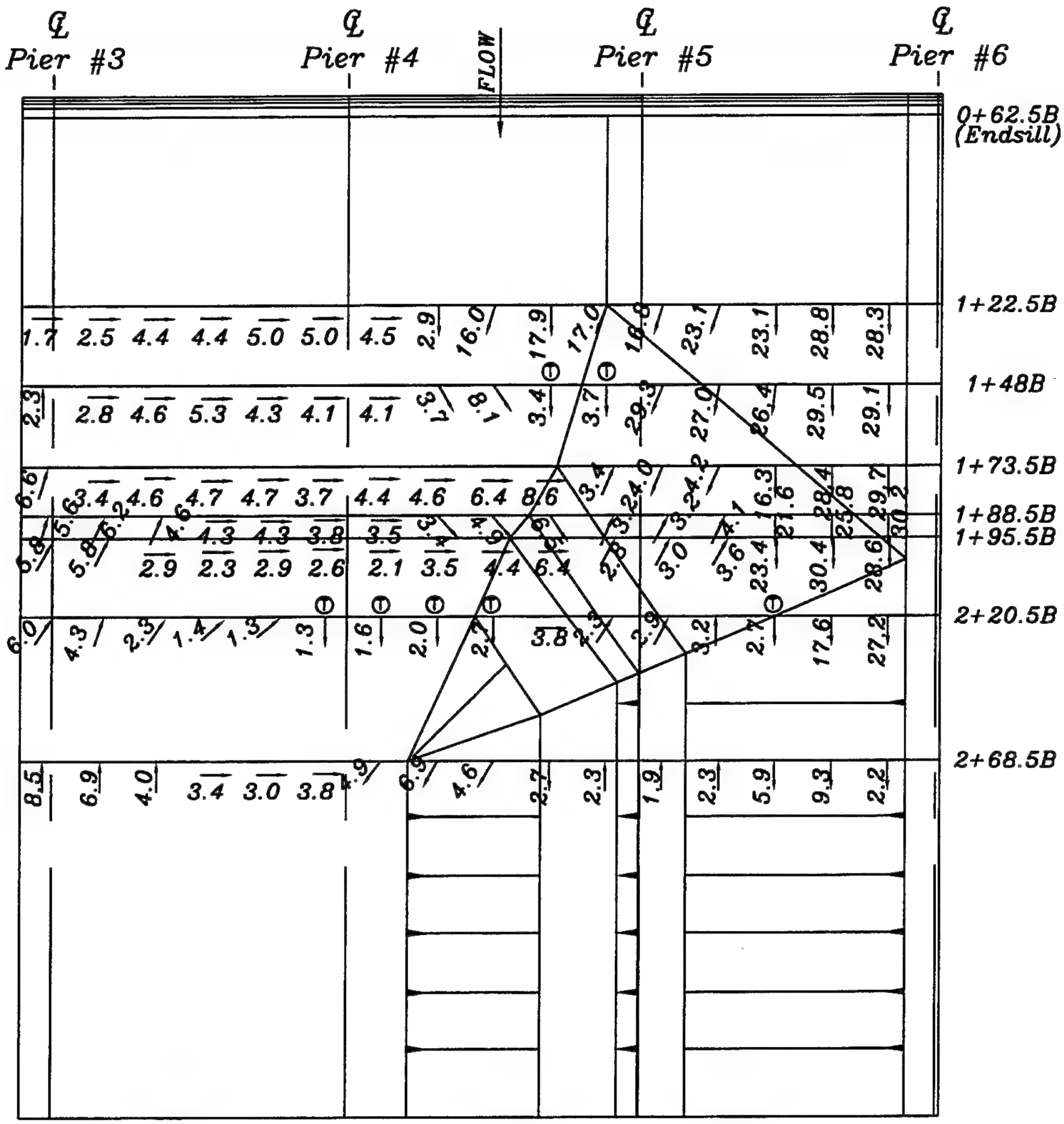


Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

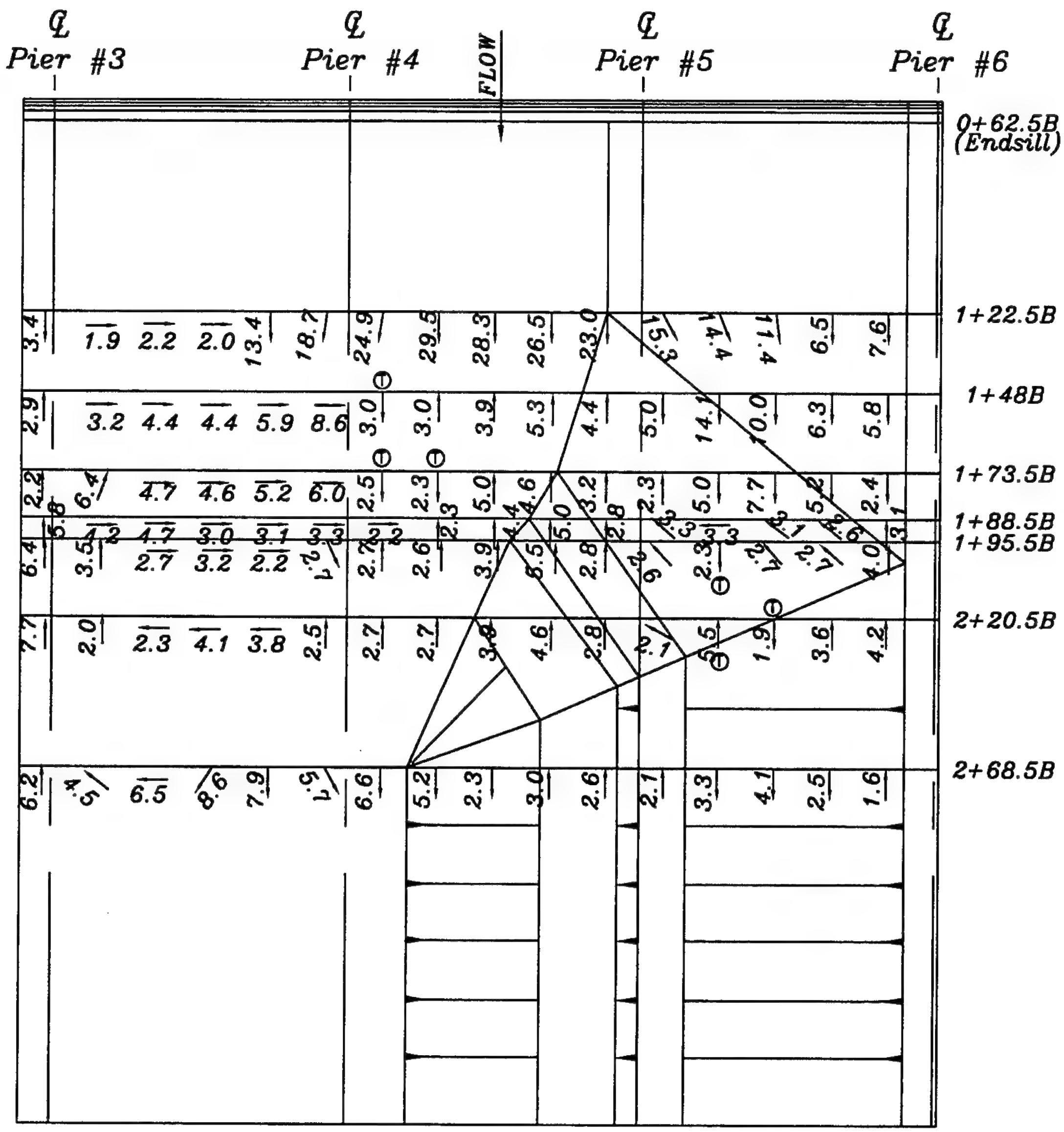
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 378 CU M/SEC (13,500 CFS)
G_3 = 0 ft, G_4 = 0 ft, G_5 = 2.4 m (8 ft)
POOL EL 743.5, TW EL 723.7



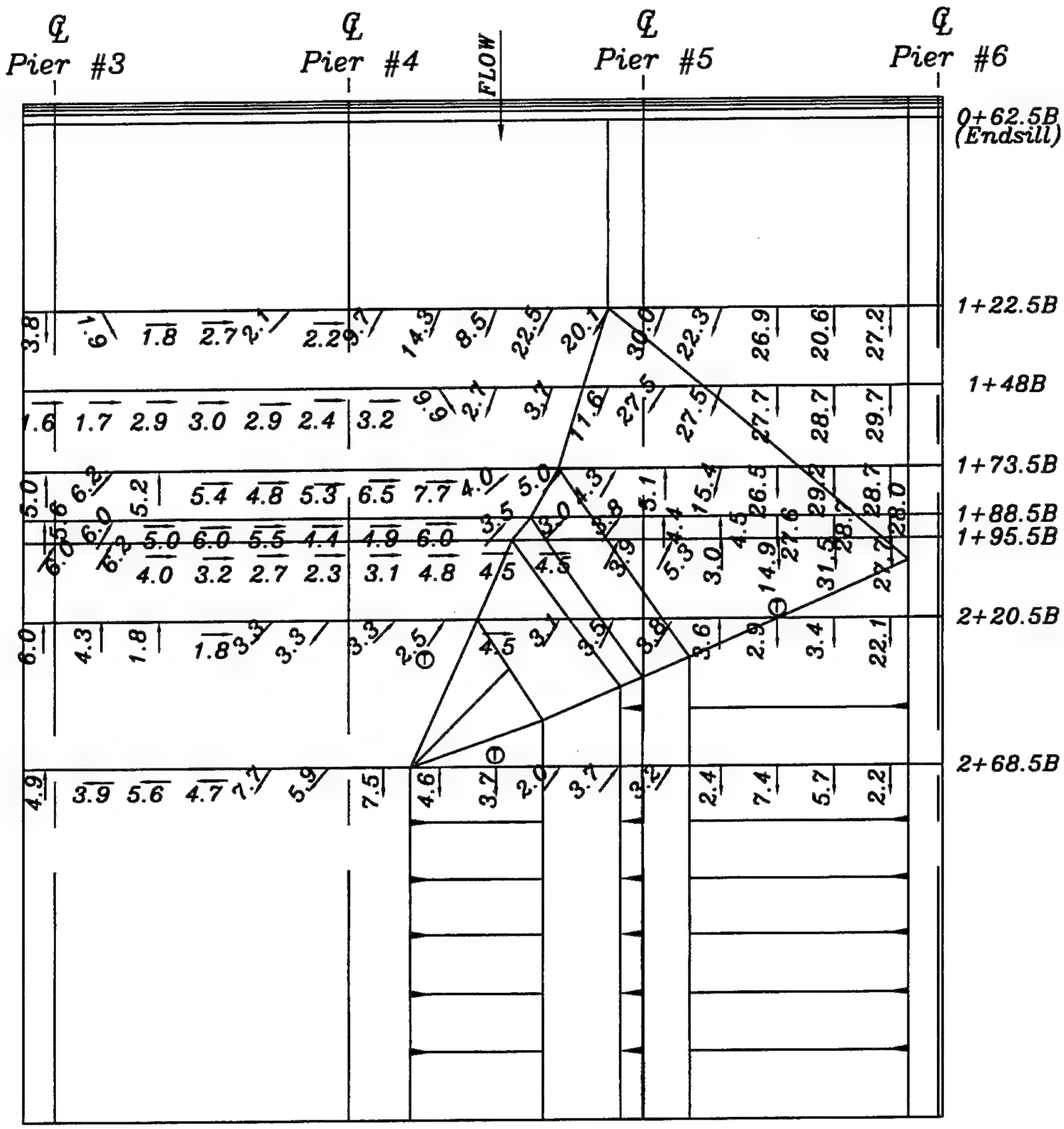
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 437 CU M/SEC (15,600 CFS)
G_3= 0 ft, G_4= 0 ft, G_5= 3.0 m (10 ft)
POOL EL 743.5, TW EL 723.7



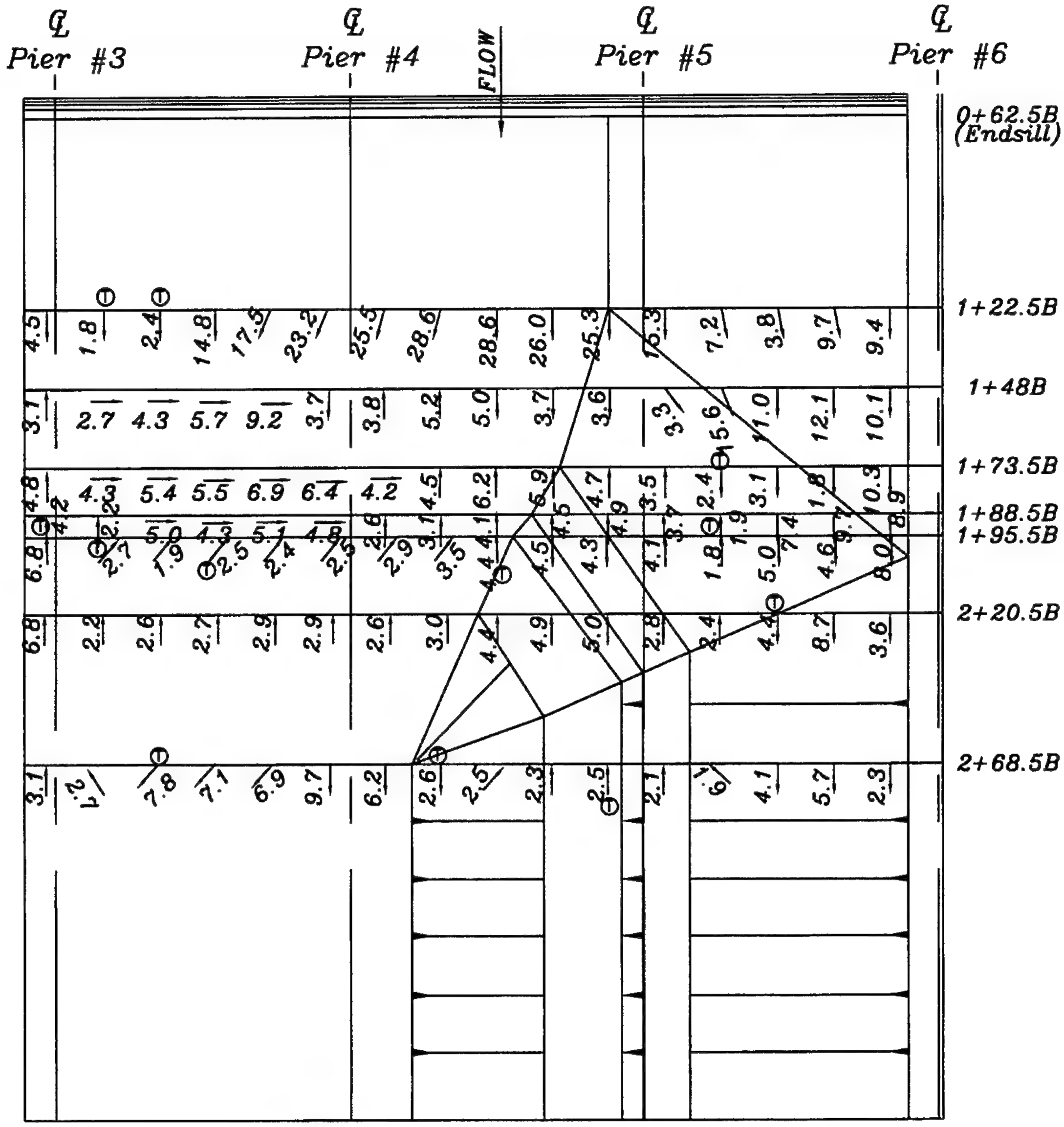
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 437 CU M/SEC (15,600 CFS)
G_3 = 0 ft, G_4 = 3.0 m (10 ft), G_5 = 0 ft
POOL EL 743.5, TW EL 723.7



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 574 CU M/SEC (20,500 CFS)
G_3 = 0 ft, G_4 = 0 ft, G_5 = FULL
POOL EL 743.5, TW EL 723.7



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

⦶ = Turbulence

BOTTOM VELOCITIES

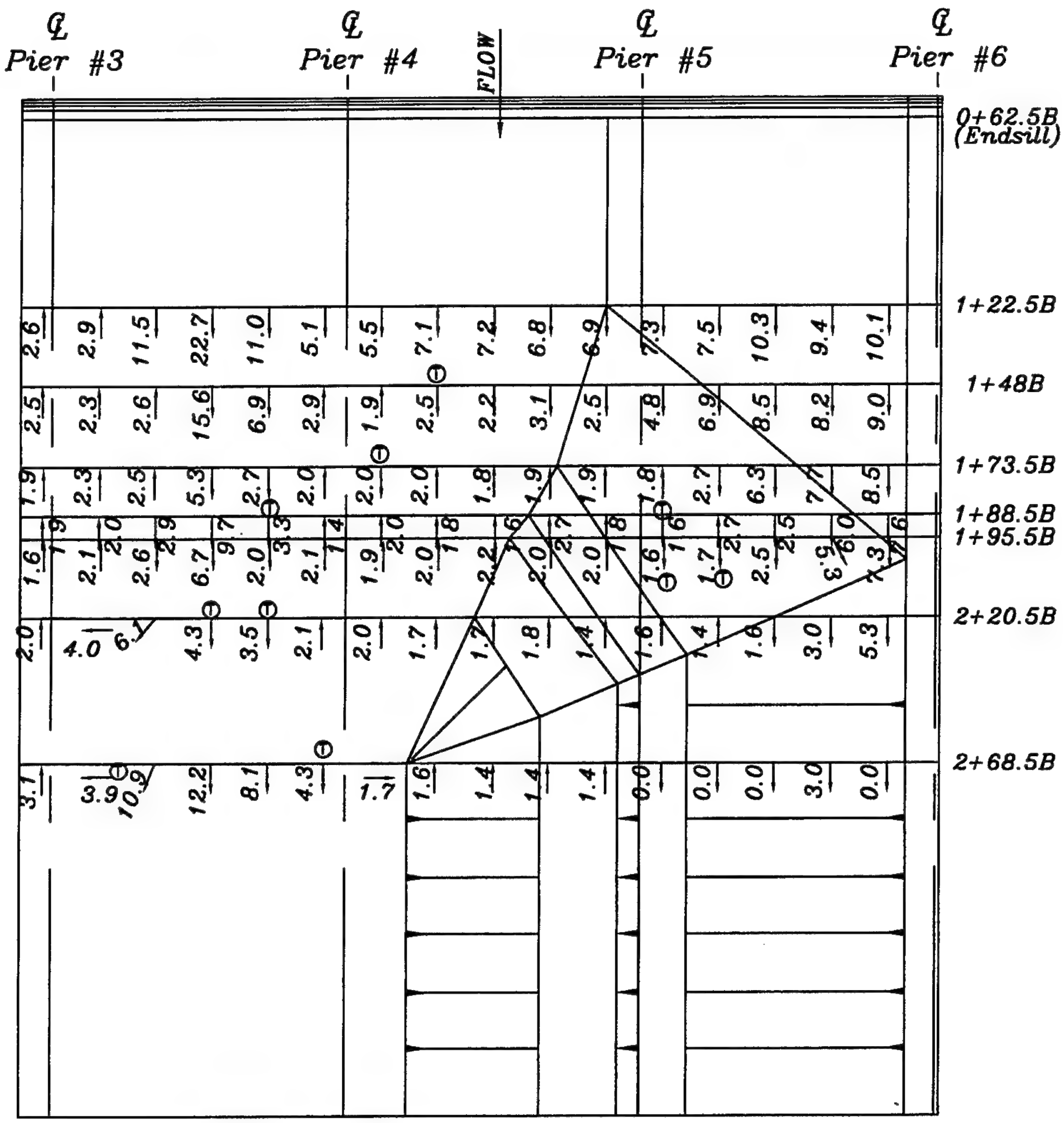
TYPE 3 RIPRAP/ROCK APRON

CONFIGURATION 2

Q = 574 CU M/SEC (20,500 CFS)

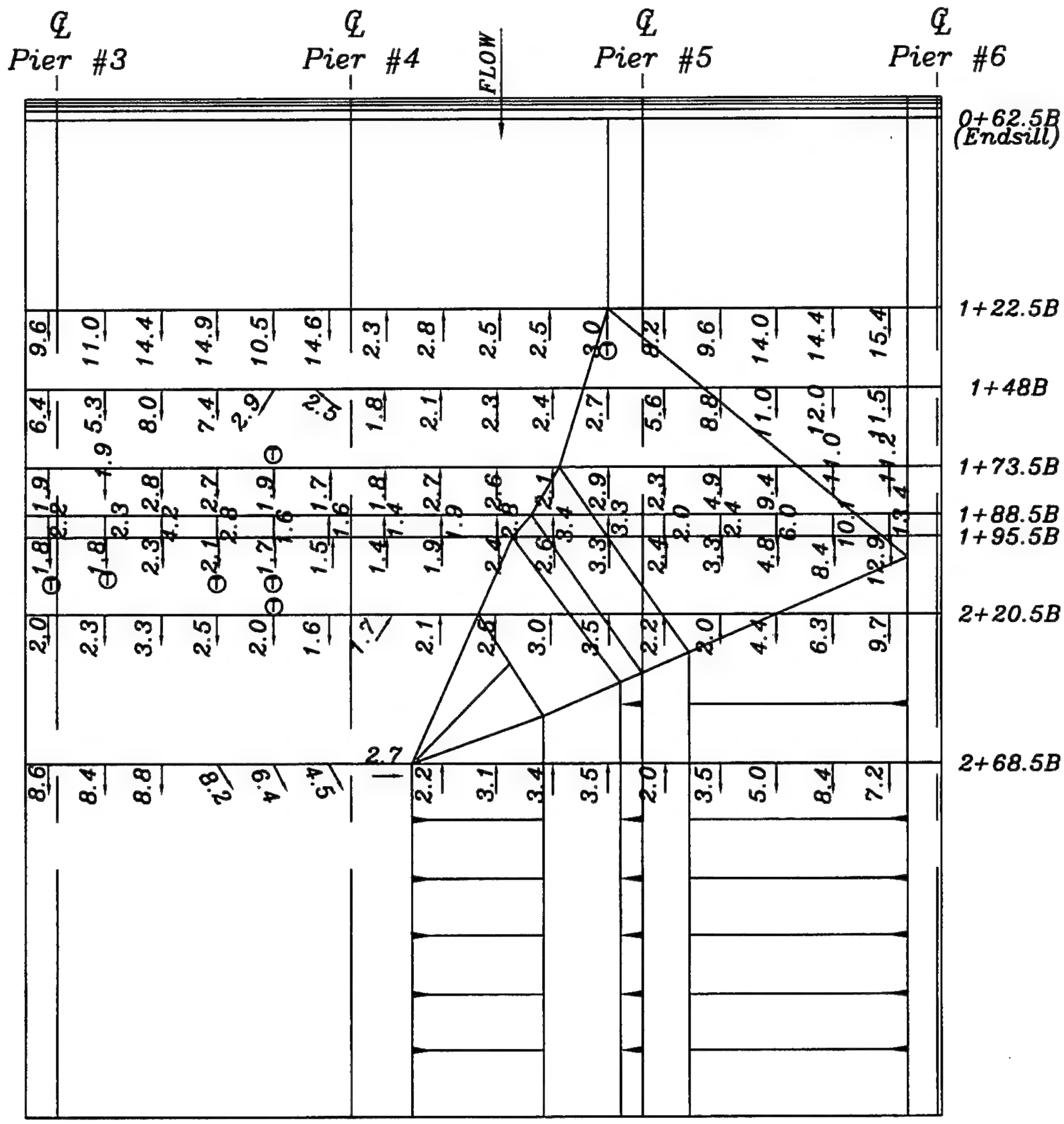
G_3 = 0 ft, G_4 = FULL, G_5 = 0 ft

POOL EL 743.5, TW EL 723.7



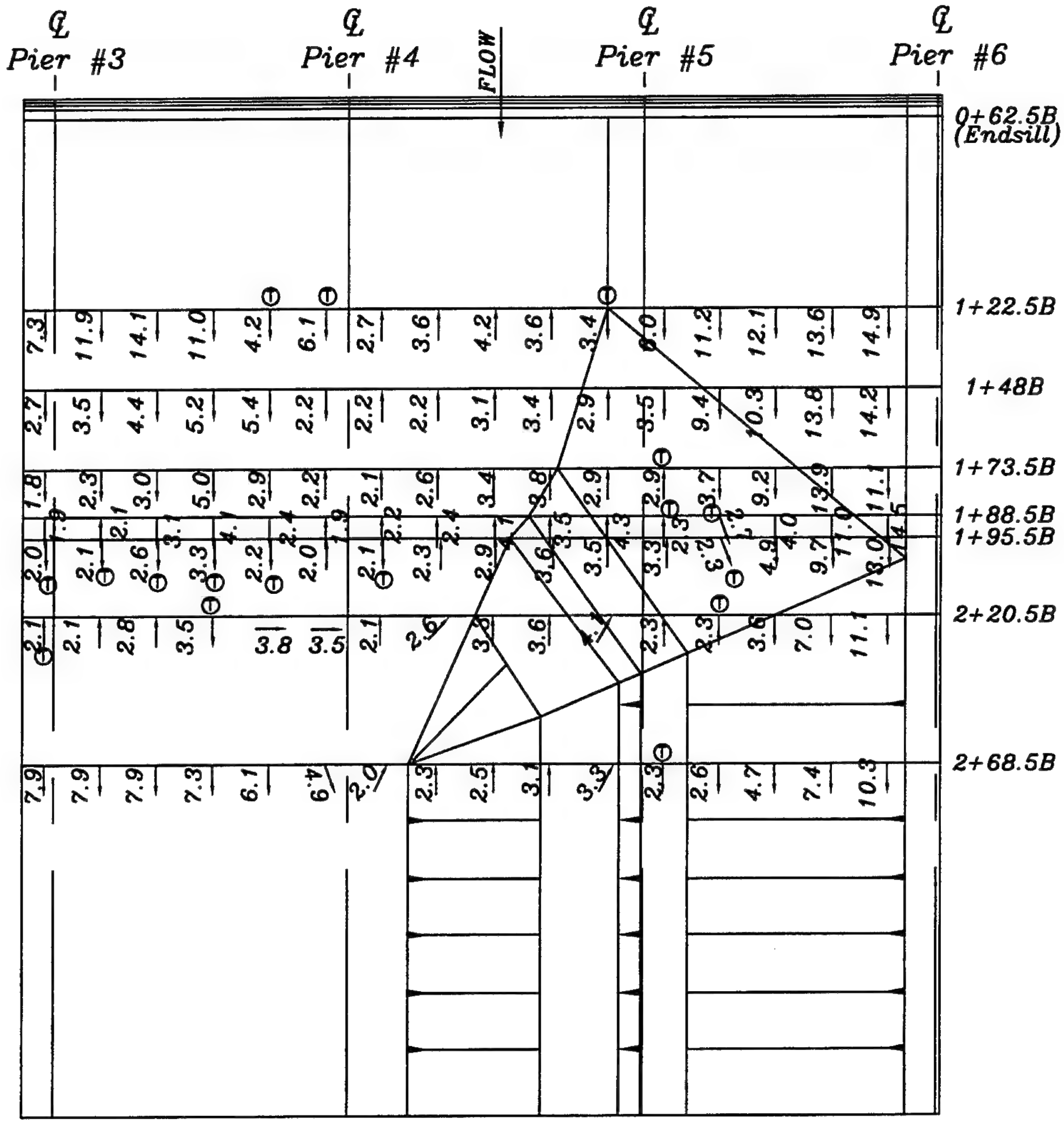
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 762 CU M/SEC (27,200 CFS)
G_3 = 1.8 m (6 ft), G_4 = 1.2 m (4 ft),
G_5 = 1.2 m (4 ft)
POOL EL 743.5, TW EL 730.6



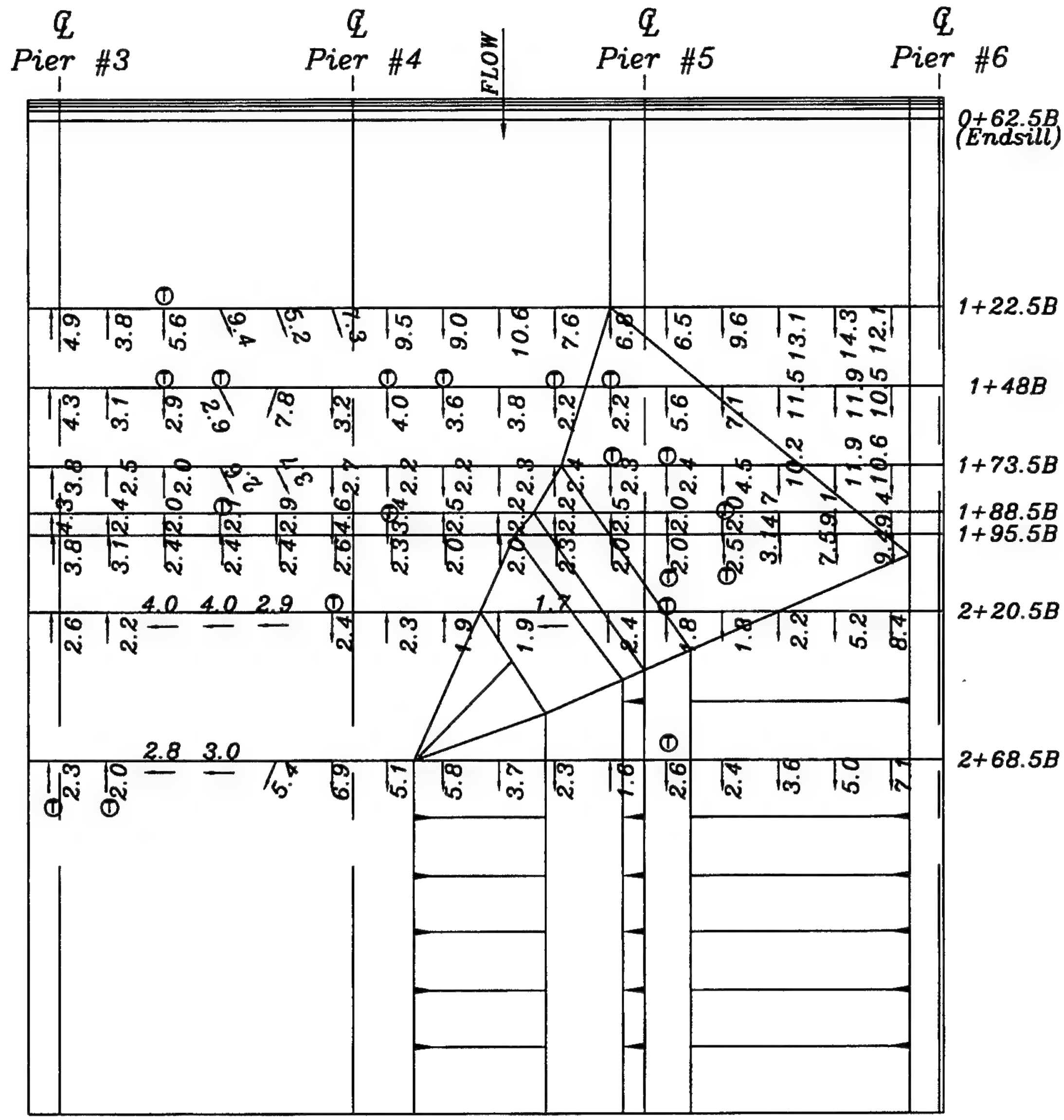
Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
⊕ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 815 CU M/SEC (29,100 CFS)
G_3= 3.0 m (10 ft), G_4= 0 ft,
G_5= 2.4 m (8 ft)
POOL EL 743.5, TW EL 733.1



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 1,078 CU M/SEC (38,500 CFS)
G_3 = FULL, G_4 = 0 ft, G_5 = 3.6 m (12 ft)
POOL EL 743.5, TW EL 736.3



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

ⓣ = Turbulence

BOTTOM VELOCITIES

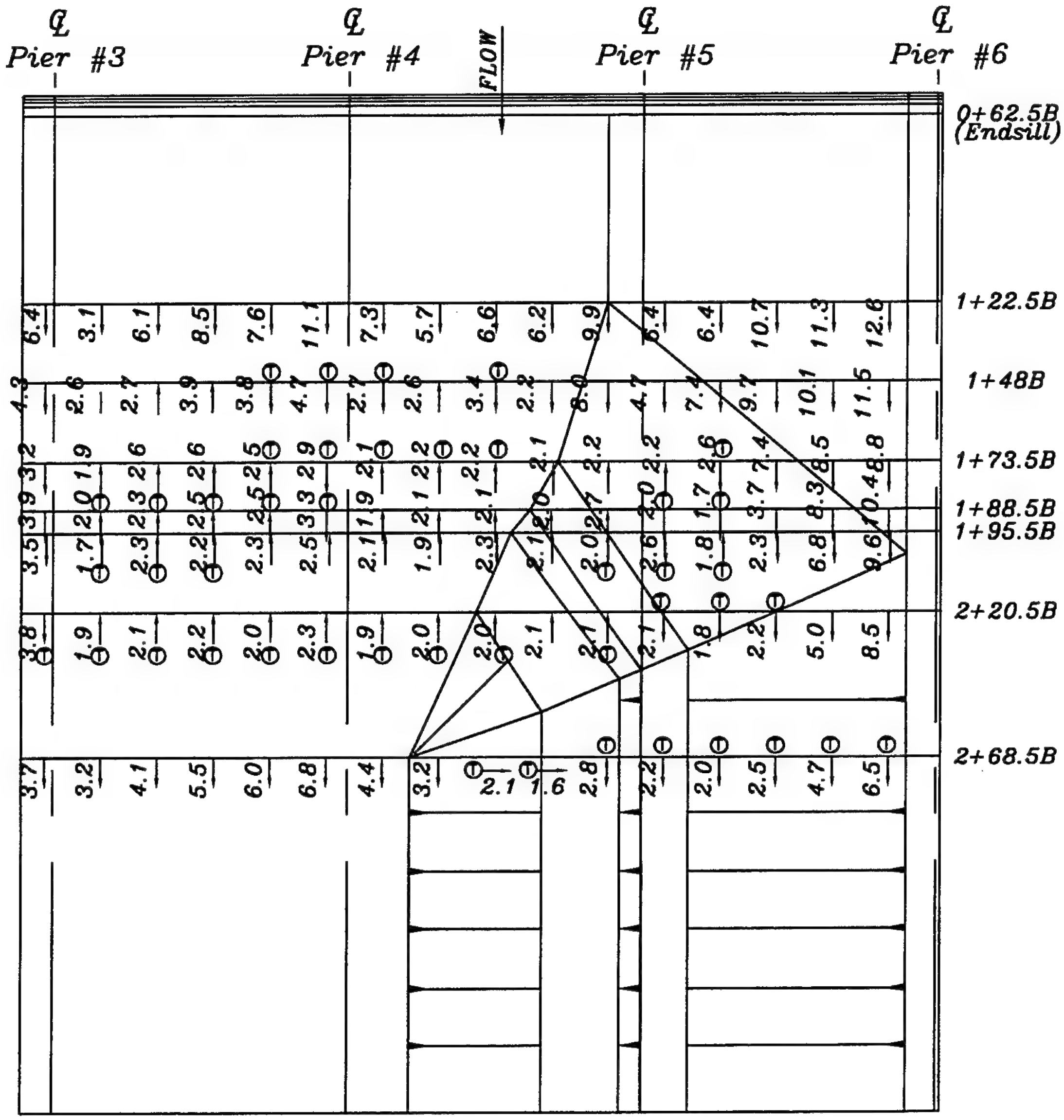
TYPE 3 RIPRAP/ROCK APRON

CONFIGURATION 2

Q = 1,193 CU M/SEC (42,600 CFS)

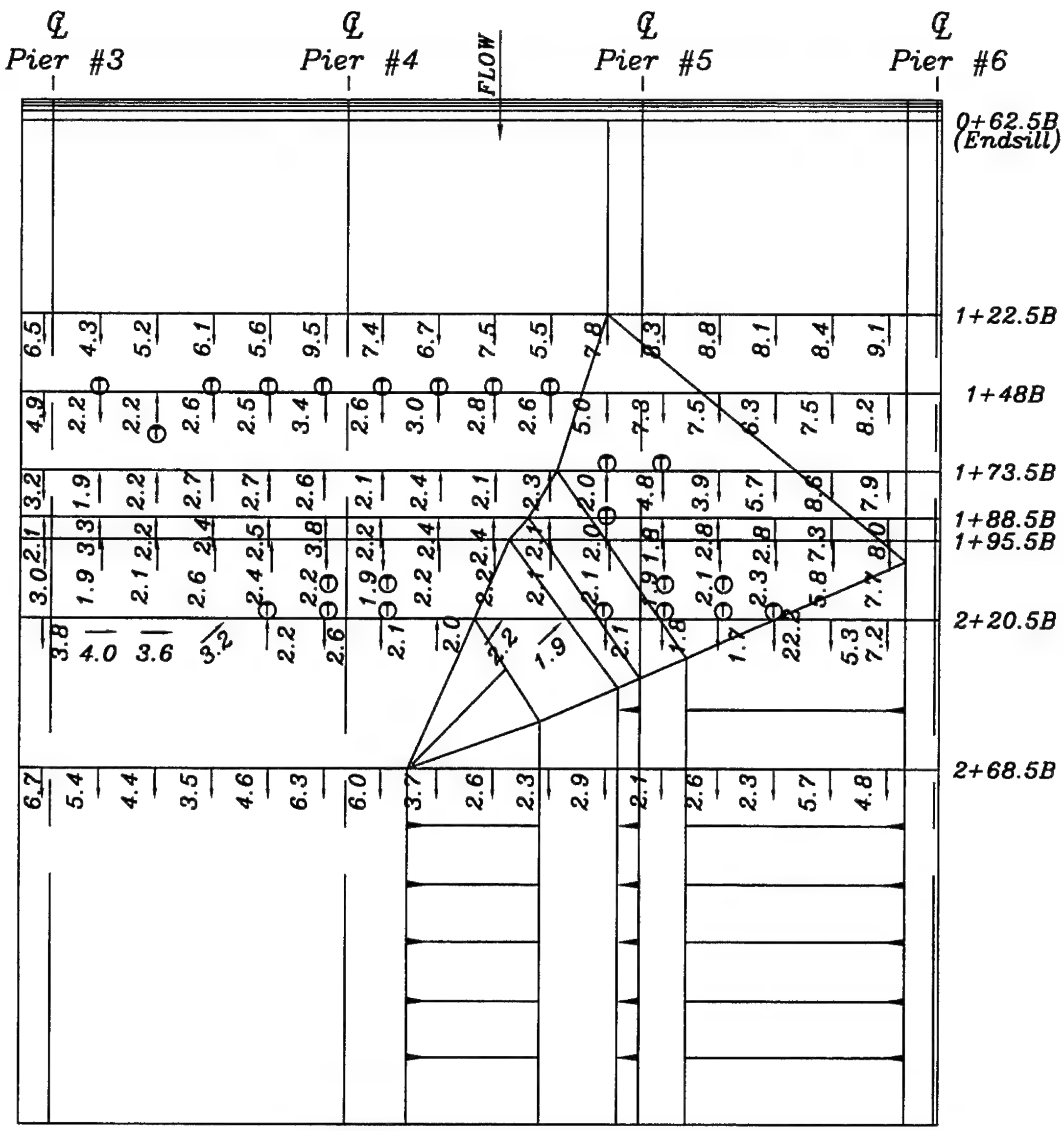
G_3 = 3.0 m (10 ft), G_4 = 2.4 m (8 ft), G_5 = 2.4 m (8 ft)

POOL EL 743.5, TW EL 735.5



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 1,366 CU M/SEC (48,800 CFS)
G_3 = 3.6 m (12 ft), G_4 = 3.0 m (10 ft),
G_5 = 3.0 m (10 ft)
POOL EL 743.5, TW EL 737.1



Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.

Note: Lateral spacing is 5.5 m (18 ft).

Ⓣ = Turbulence

BOTTOM VELOCITIES

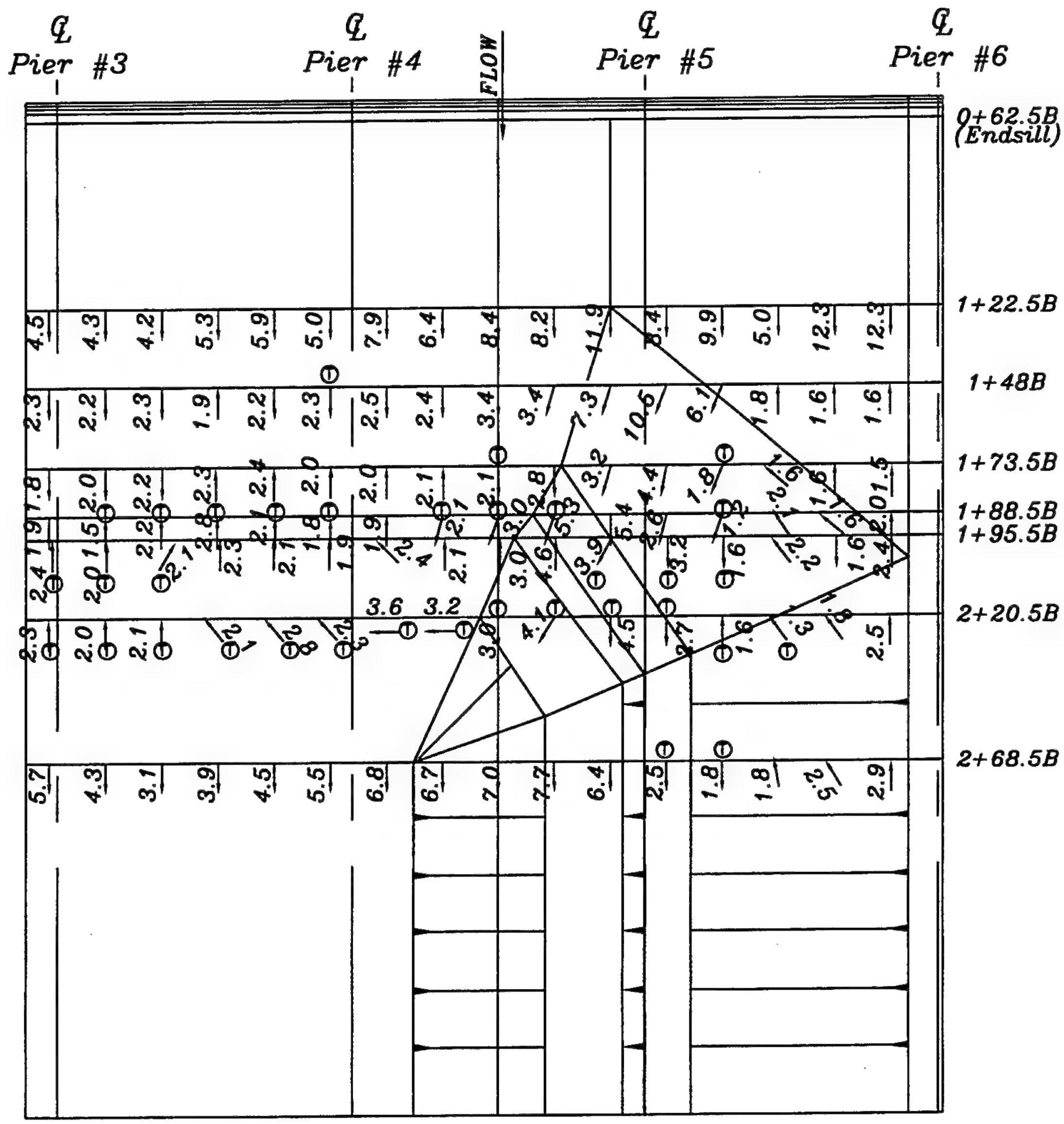
TYPE 3 RIPRAP/ROCK APRON

CONFIGURATION 2

Q = 1,537 CU M/SEC (54,900 CFS)

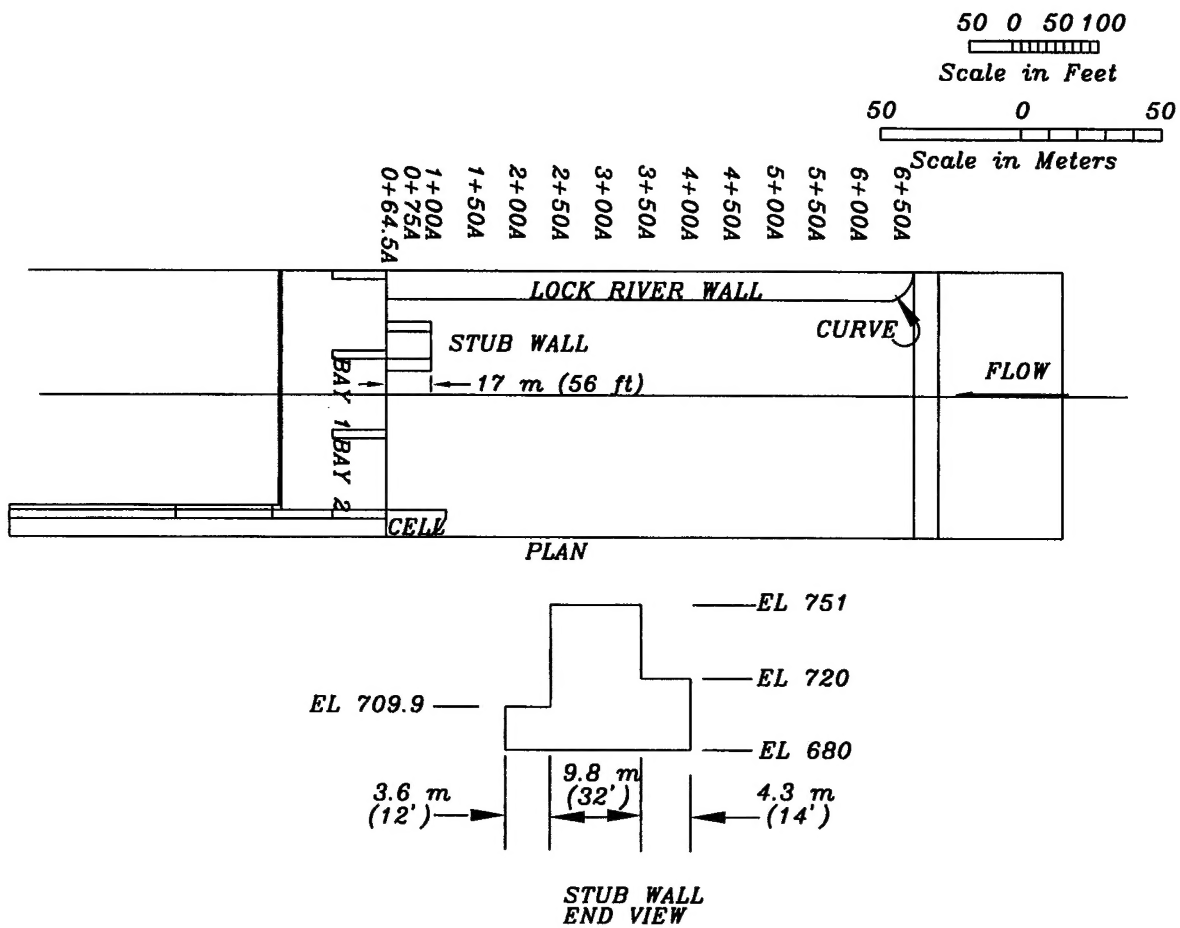
G_3 = FULL, G_4 = 3.6 m (12 ft), G_5 = 3.6 m (12 ft)

POOL EL 743.5, TW EL 739.0

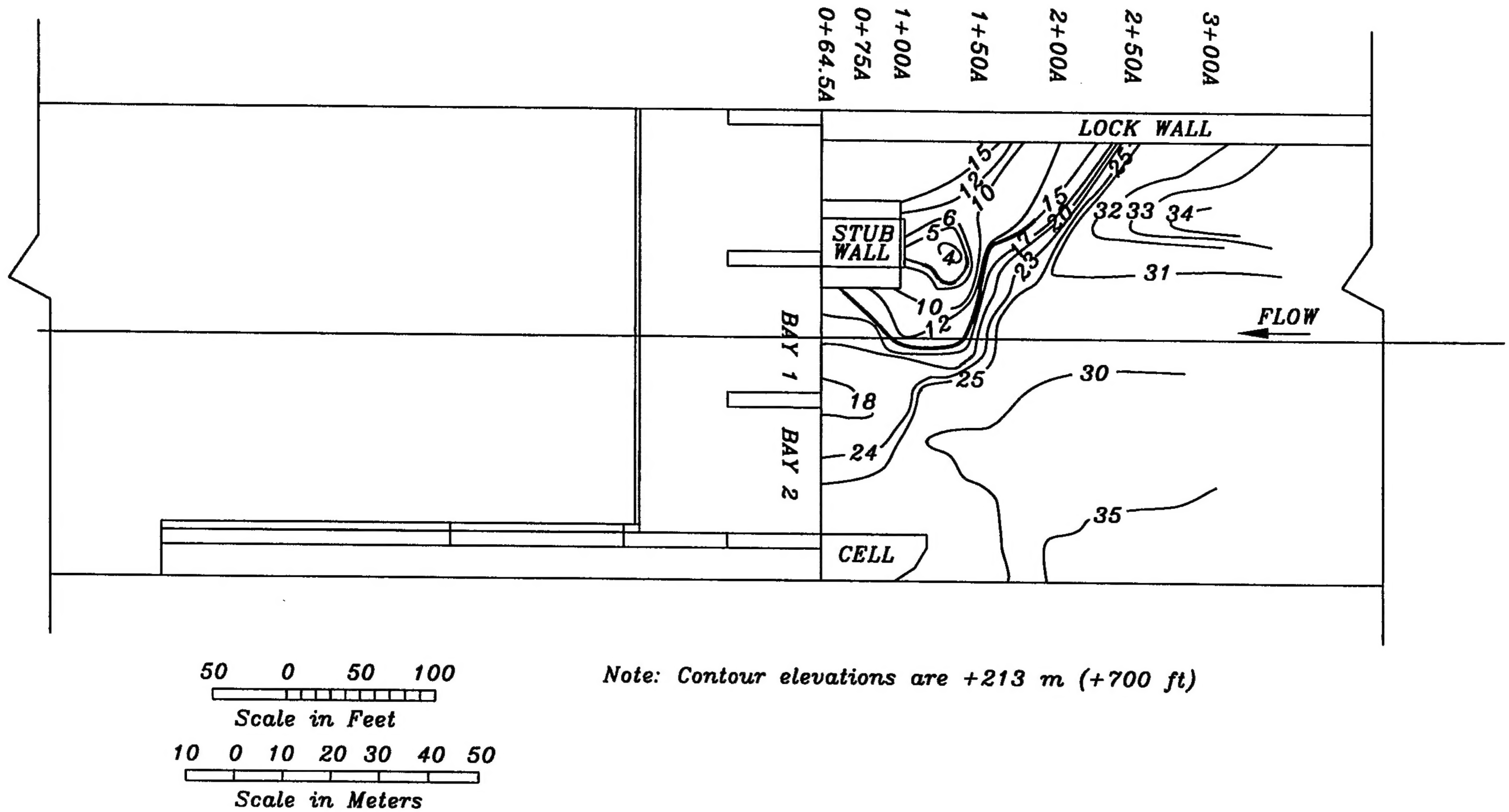


Velocities are measured 1 m (3.6 ft) above riprap and are given in ft/sec. To convert to m/sec, multiply by 0.3048.
Note: Lateral spacing is 5.5 m (18 ft).
Ⓣ = Turbulence

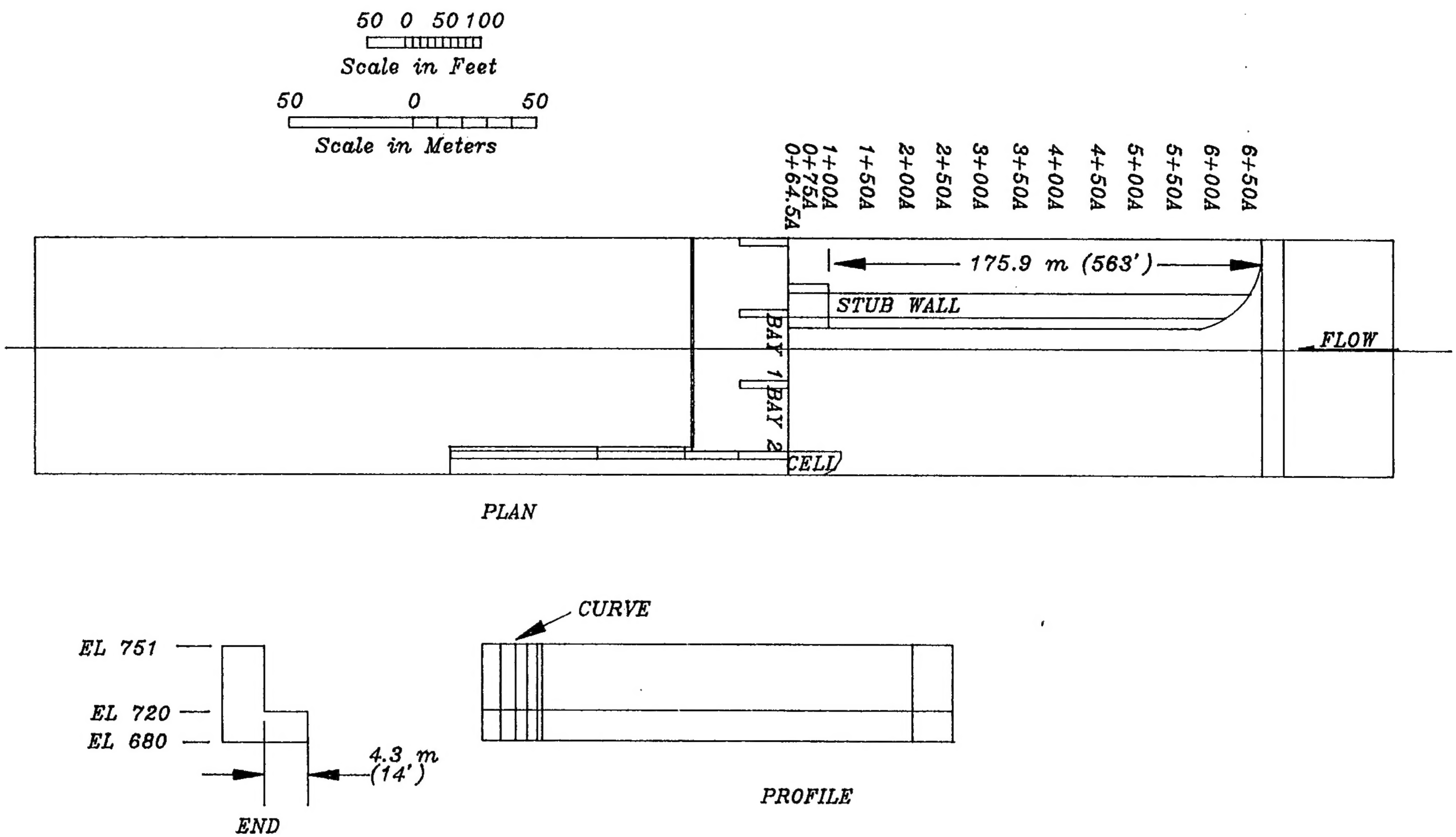
BOTTOM VELOCITIES
TYPE 3 RIPRAP/ROCK APRON
CONFIGURATION 2
Q = 1,630 CU M/SEC (58,200 CFS)
G_3 = FULL, G_4 = FULL, G_5 = FULL
POOL EL 743.5, TW EL 740.3



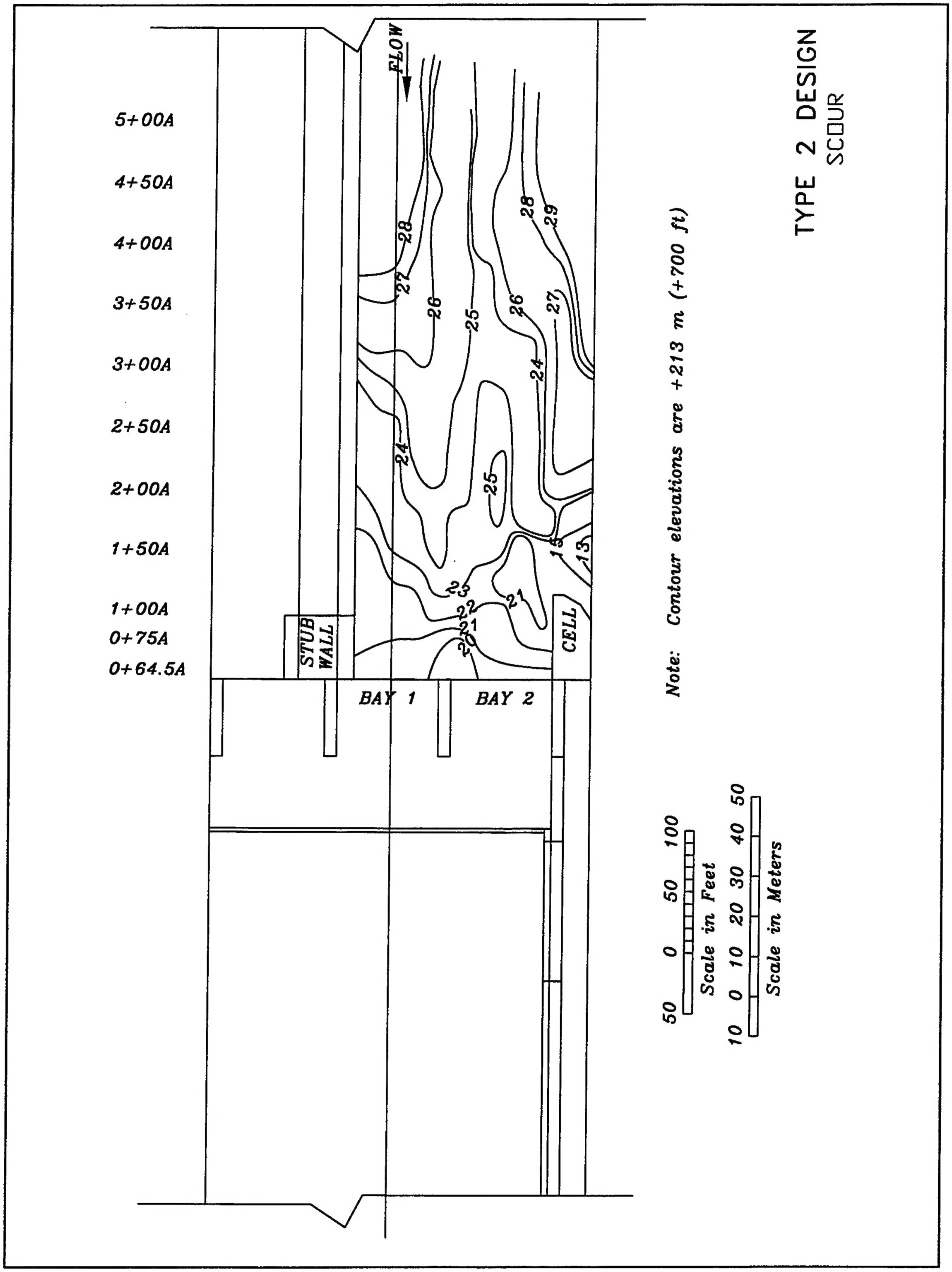
TYPE 1 (ORIGINAL)
STUB WALL



TYPE 1 STUB WALL
SCOUR



TYPE 2
STUB WALL


TYPE 2 DESIGN
SCOUR
Note: Contour elevations are +213 m (+700 ft)
FLOW
5+00A
4+50A
4+00A
3+50A
3+00A
2+50A
2+00A
1+50A
1+00A
0+75A
0+64.5A
STUB WALL
CELL
BAY 1
BAY 2
Scale in Feet
50 0 50 100
Scale in Meters
10 0 10 20 30 40 50